NIR Detectors

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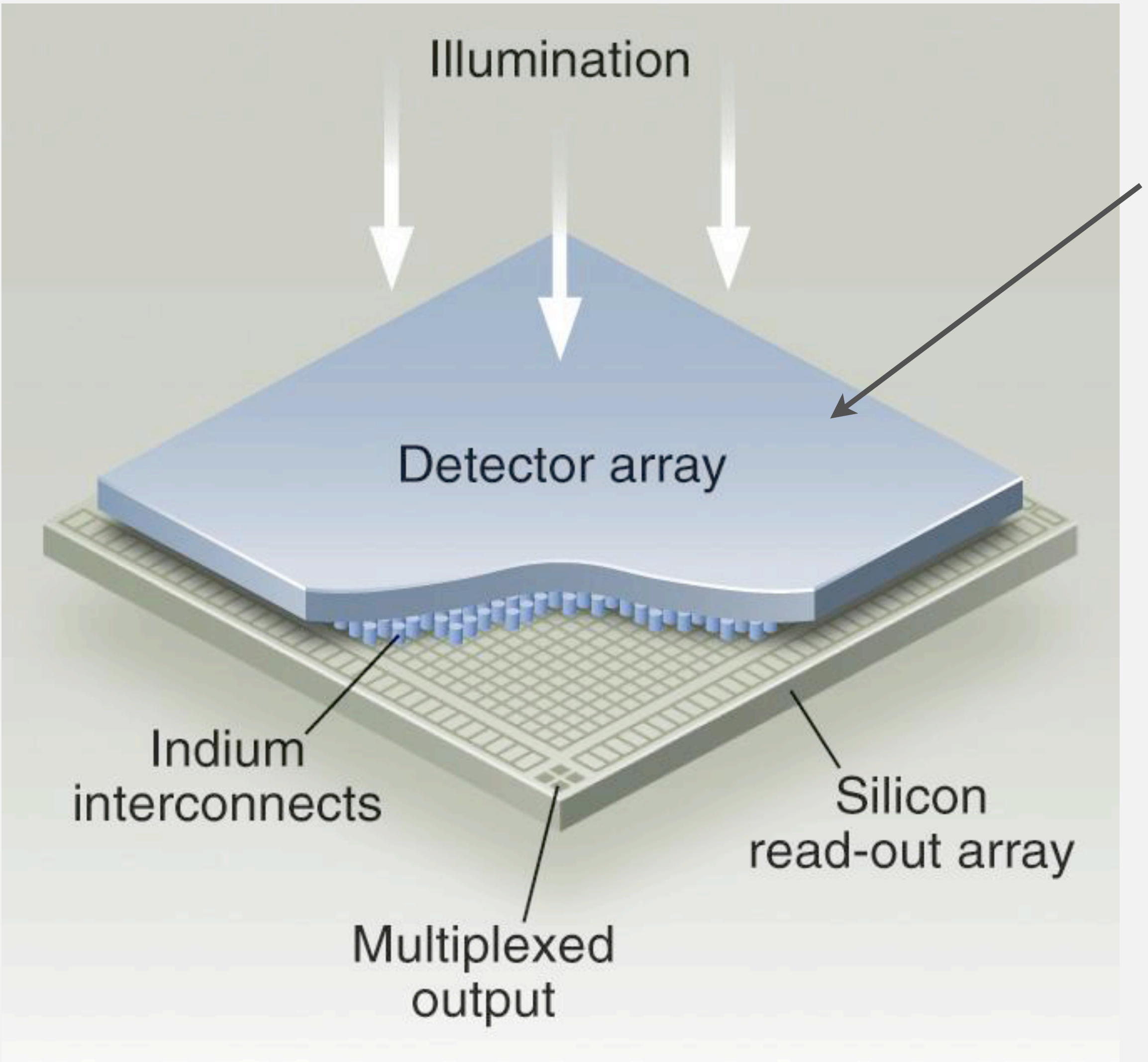
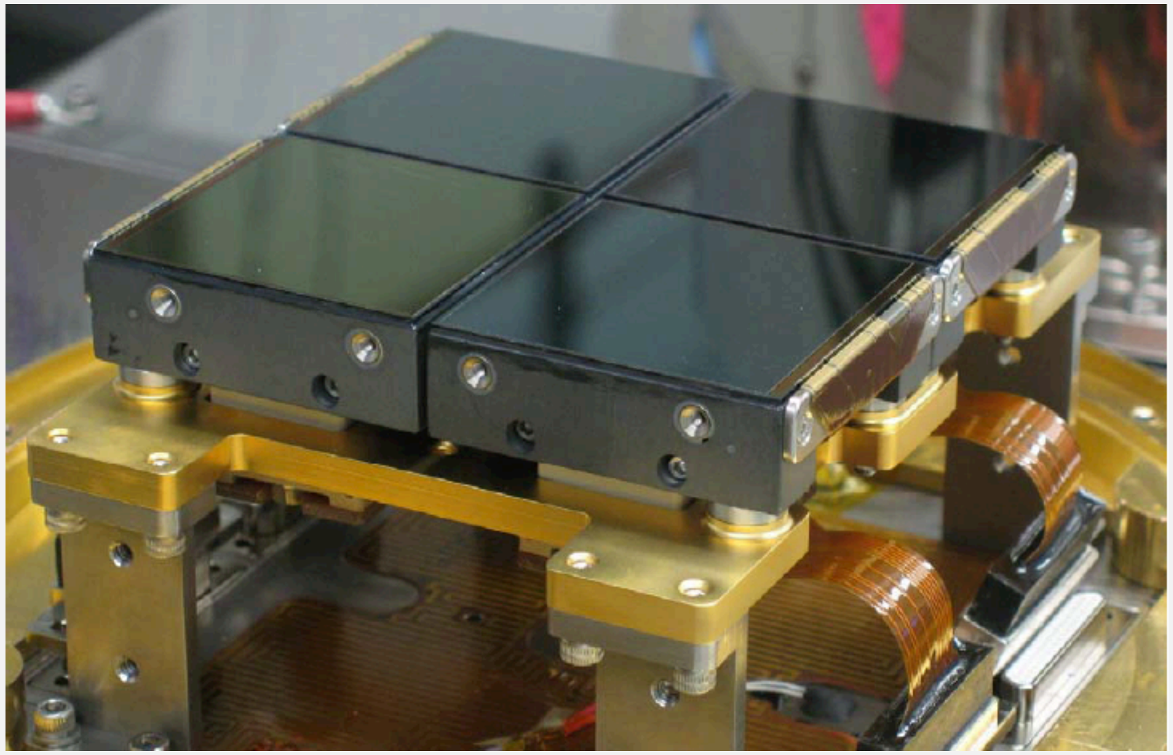
BigBOSS Collaboration Meeting
LBL

Hybrid (NIR) Imaging Sensors



NIR: HgCdTe detector layer w/ tailored wavelength cut-off



Operation & performance

- No charge transfer (every pixel has its own MOSFET)
- Fast multiplexed (selective) read-out

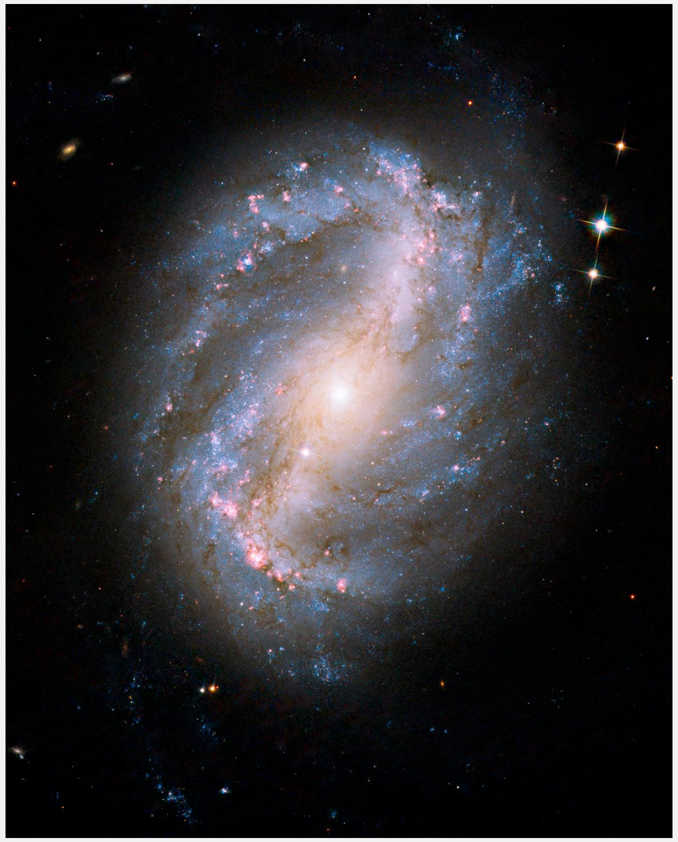
- Dark current higher than CCDs (strong function of temp., cut-off)
- Read noise higher than CCDs (≤25 e / CDS for 1.7μm; ≤10 e / CDS for 1.7μm)

- Multiple non-destructive sampling possible → $\sqrt{N}$ read noise

- Interpixel capacitance – deterministic coupling
- Persistence – short term memory of prior exposure(s)
- Flux dependent gain (?)

SIDECAR ASIC:
digitizing & control integrated in single chip

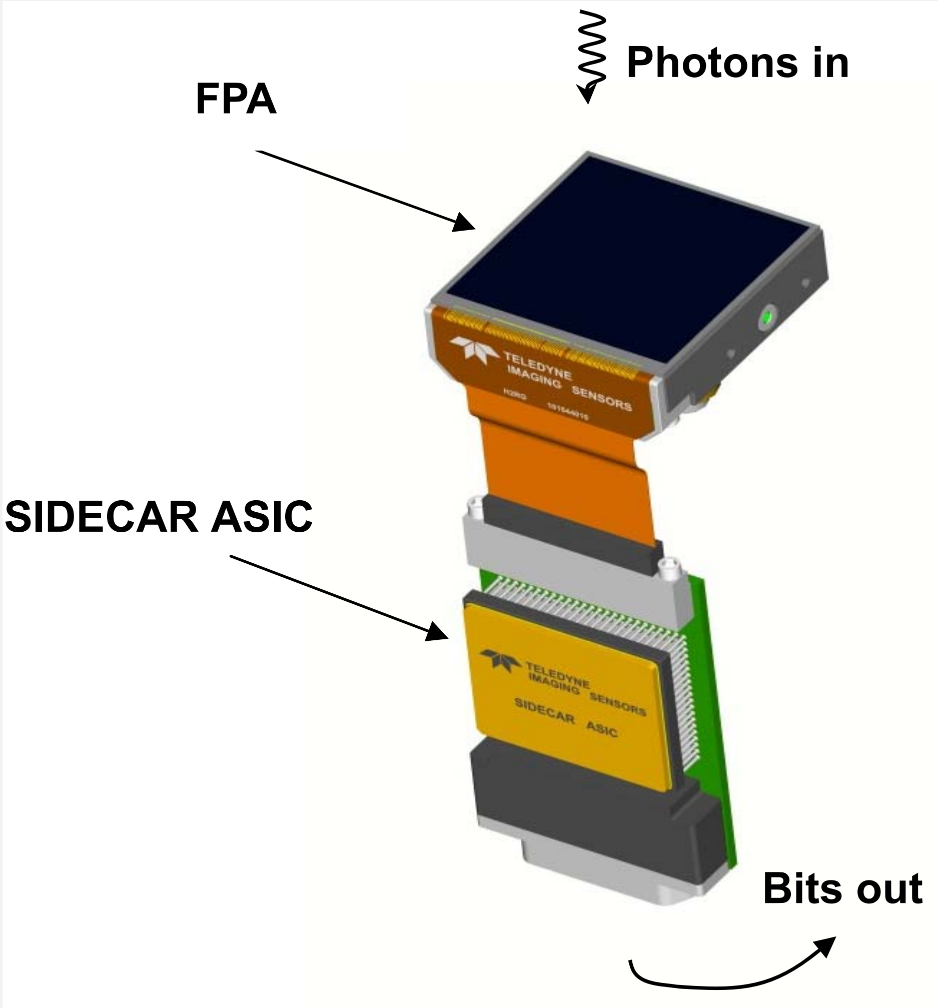
- will be used for JWST
- installed during HST service mission 4 to read ACS CCD
- cryo or warm operation possible
- Sidecar module + EGSE developed for SNAP/JDEM



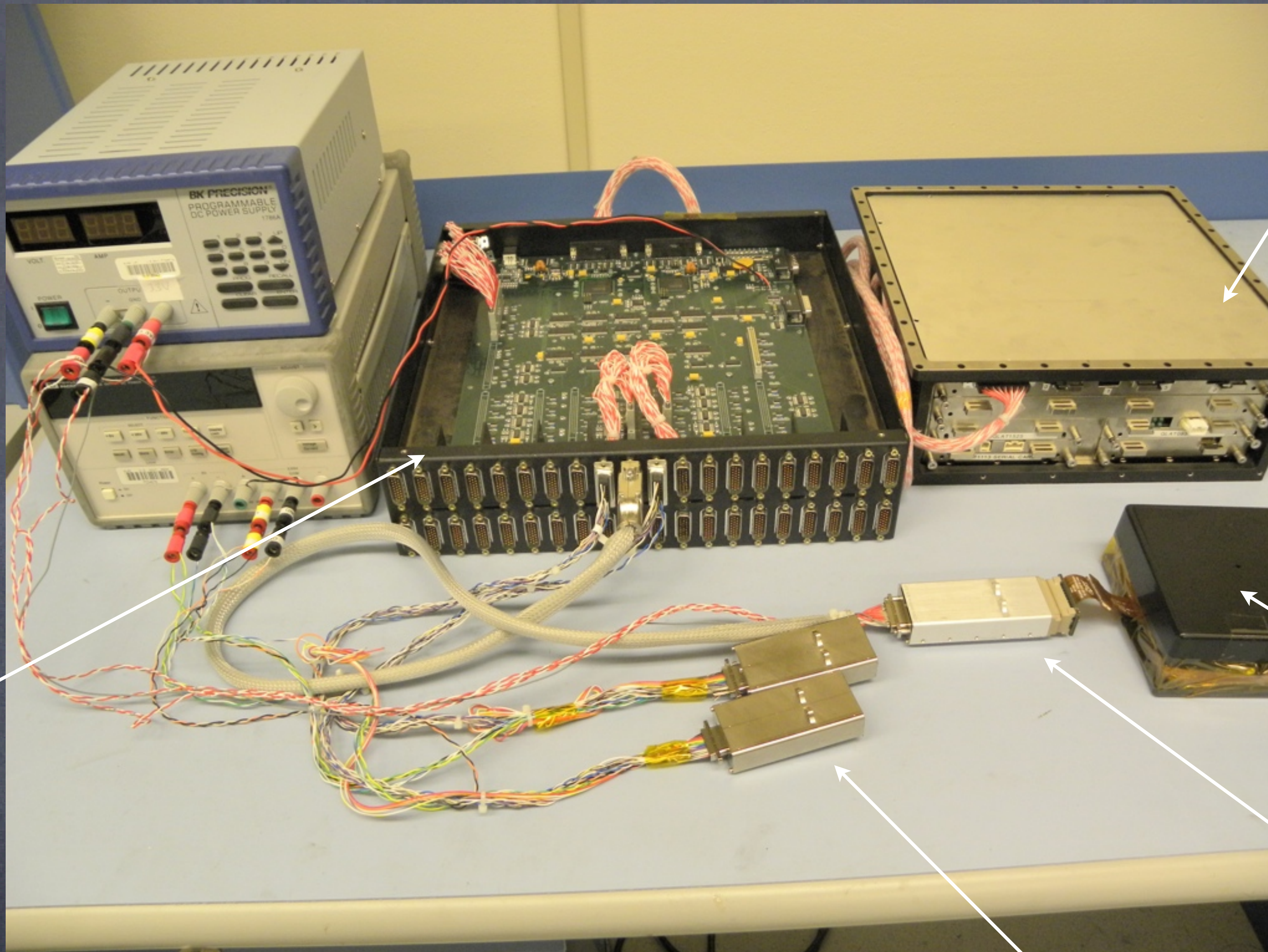
First Image of the Repaired Advanced Camera for Surveys

Barred Spiral Galaxy NGC 6217

Photographed on June 13 and July 8 2009



Flight-like-like test setup



ICU – RAD750, communi-cation board

Bare H2RG

SLAC package w/ SIDECAR

FSIM – routing, fanout, buffering, preprocessing

@ SLAC

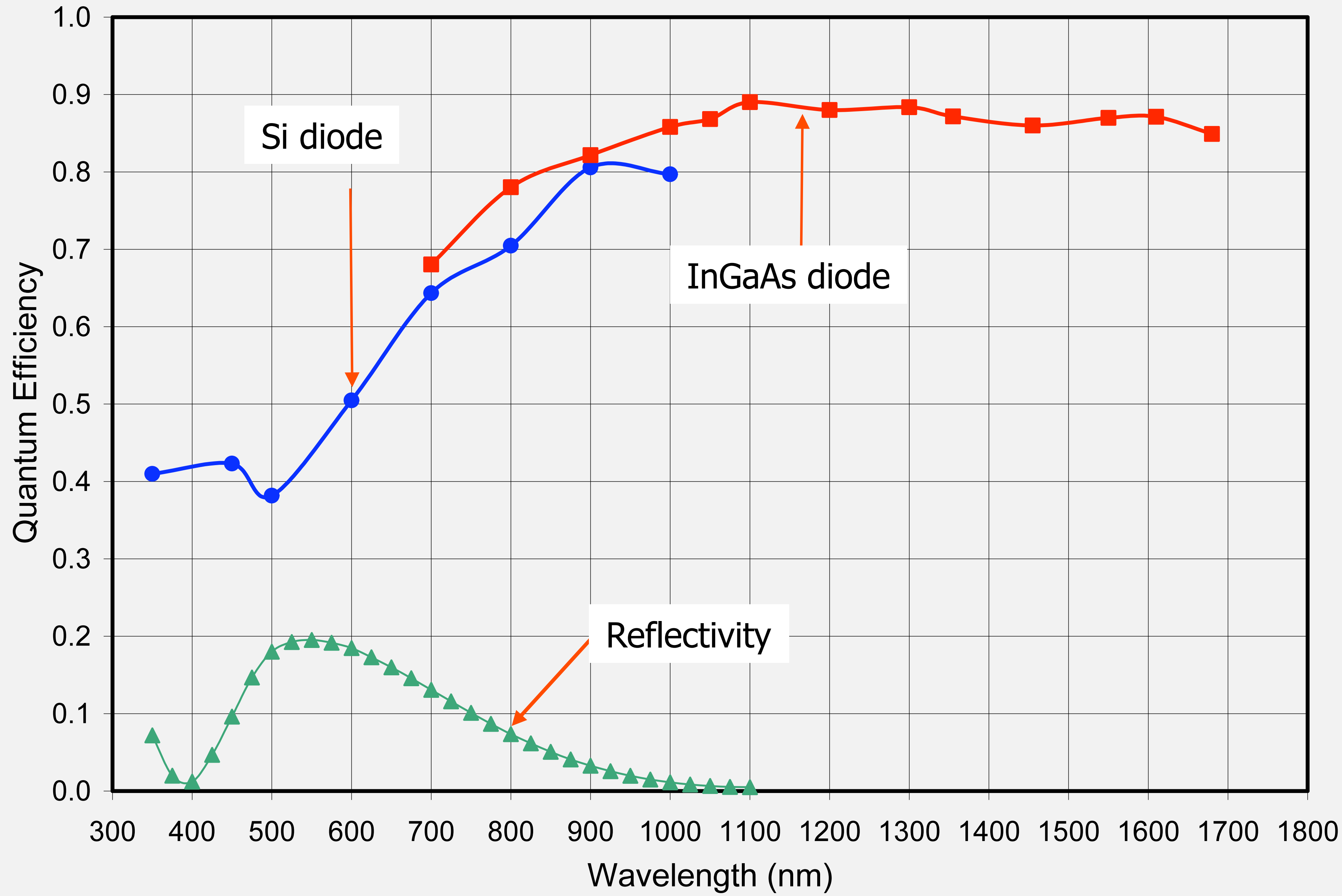
Extensive NIR effort for SNAP/JDEM

- comprehensive detector development program

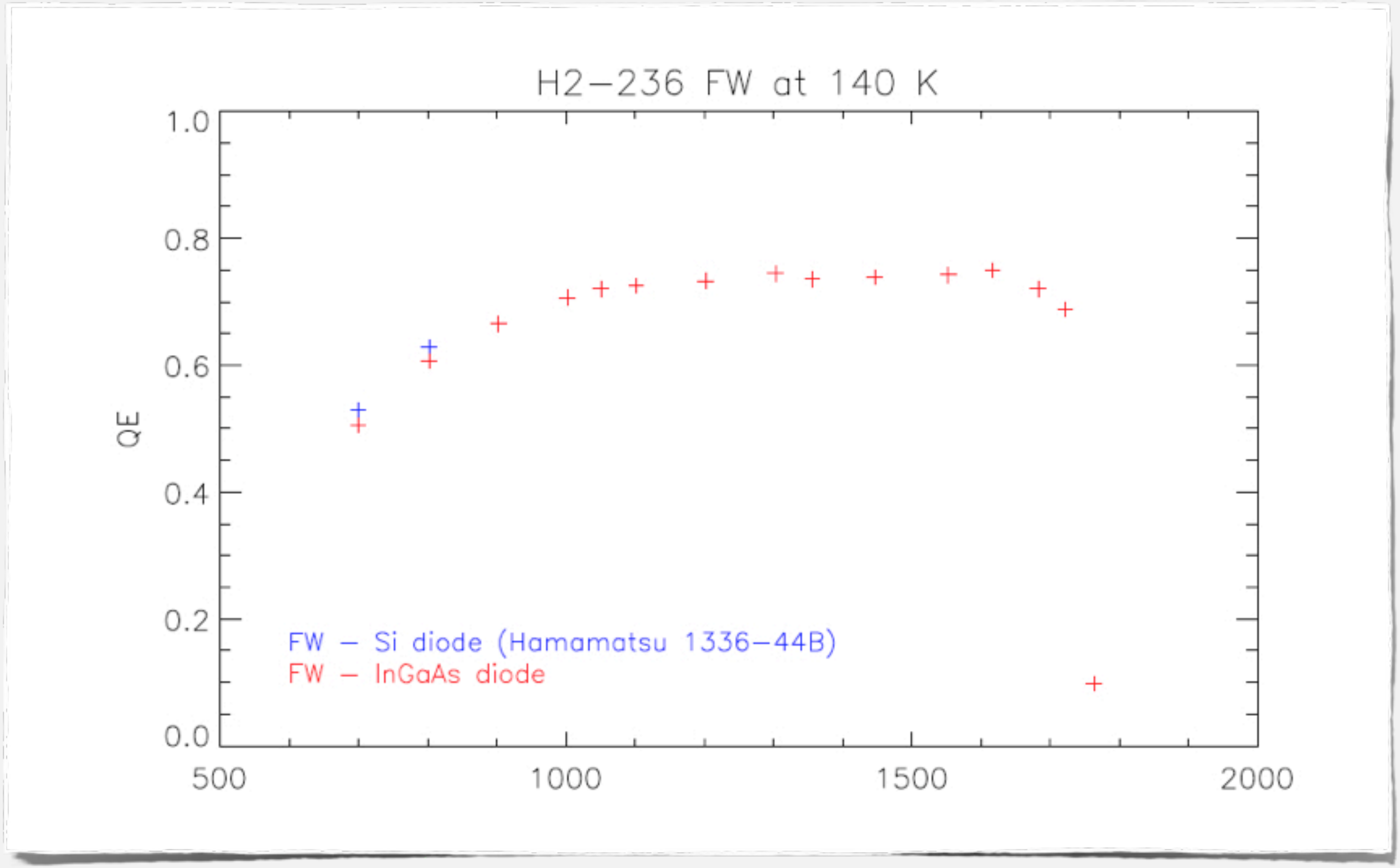
- detailed characterization w/ goal of understanding detector properties

QE (absolute and spacial)
Read-noise (total incl. dark current)
Interpixel capacitance - conversion gain
Pixel response uniformity
Linearity (fluence dependent gain)
Reciprocity failure (flux dependent gain)

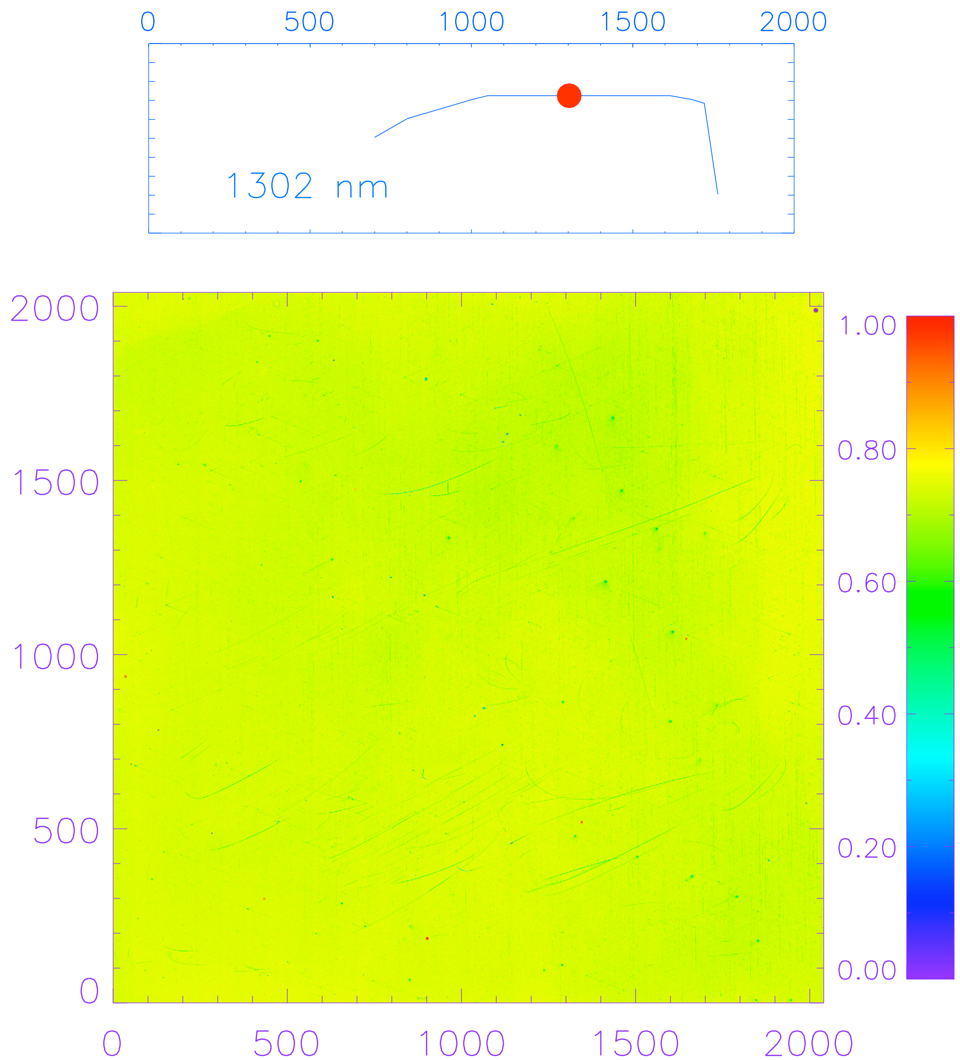
Quantum Efficiency



H2-236 QE (FILTER)



QE can be very uniform



H2RG-236

Quantum Efficiency

Wavelength: 1300 nm

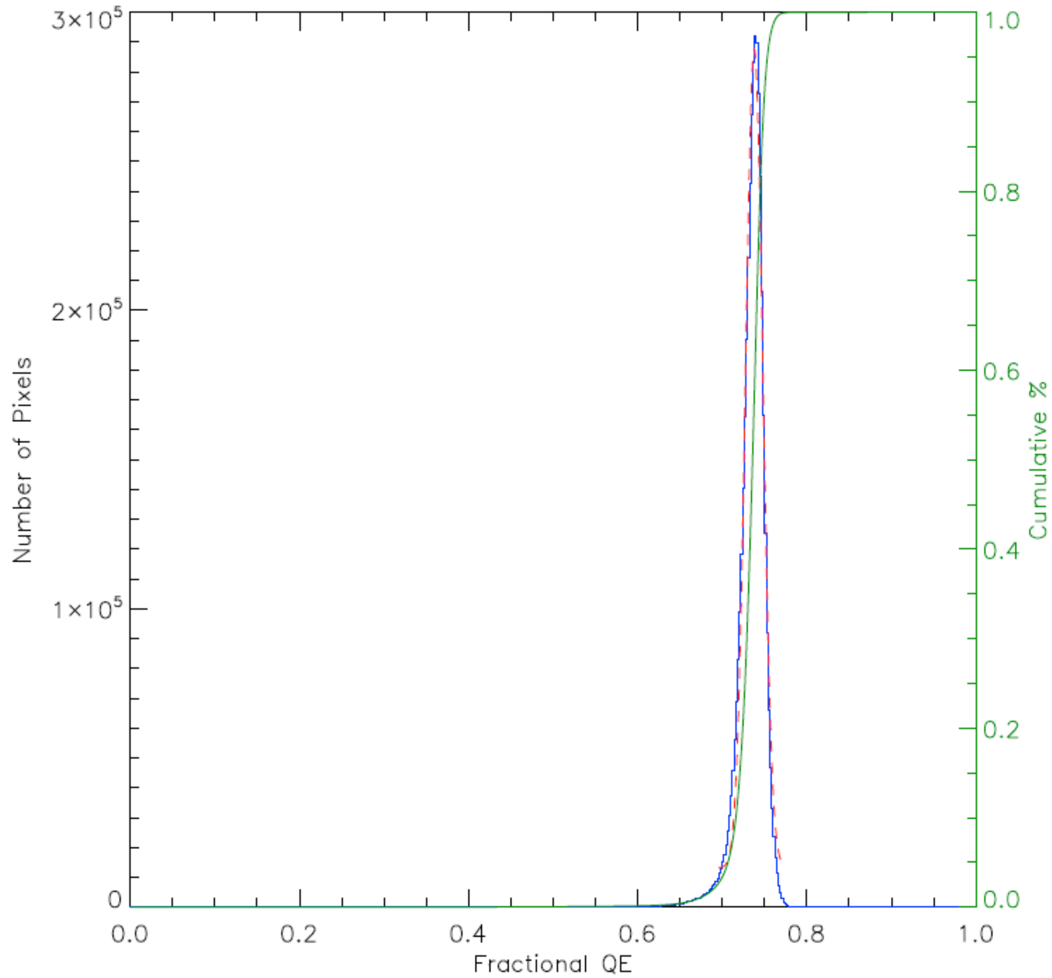
QE mean: 0.74

QE median: 0.74

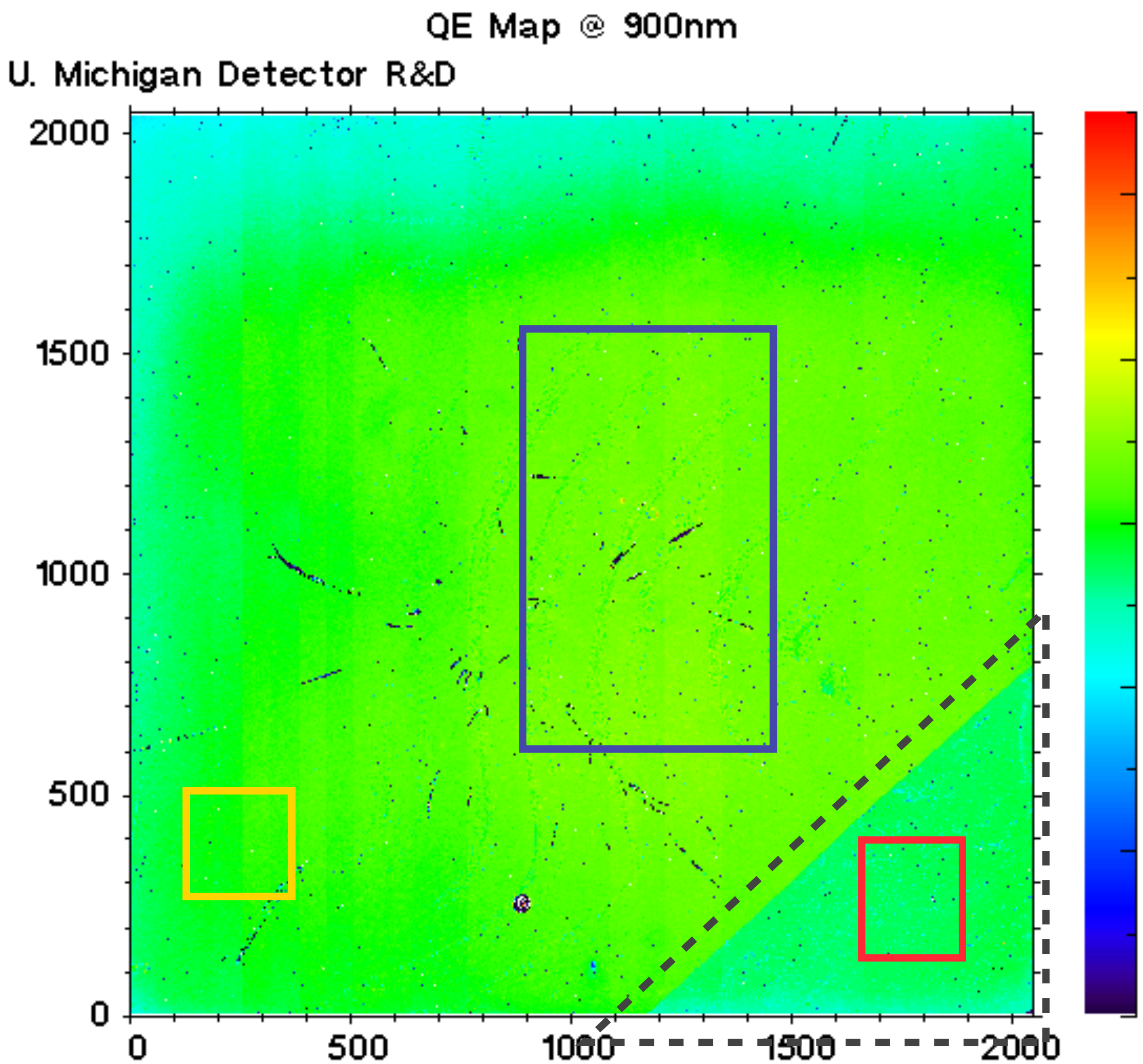
QE stdev: 0.01(1.4%)

PIX (QE>35%): 99.9ξ

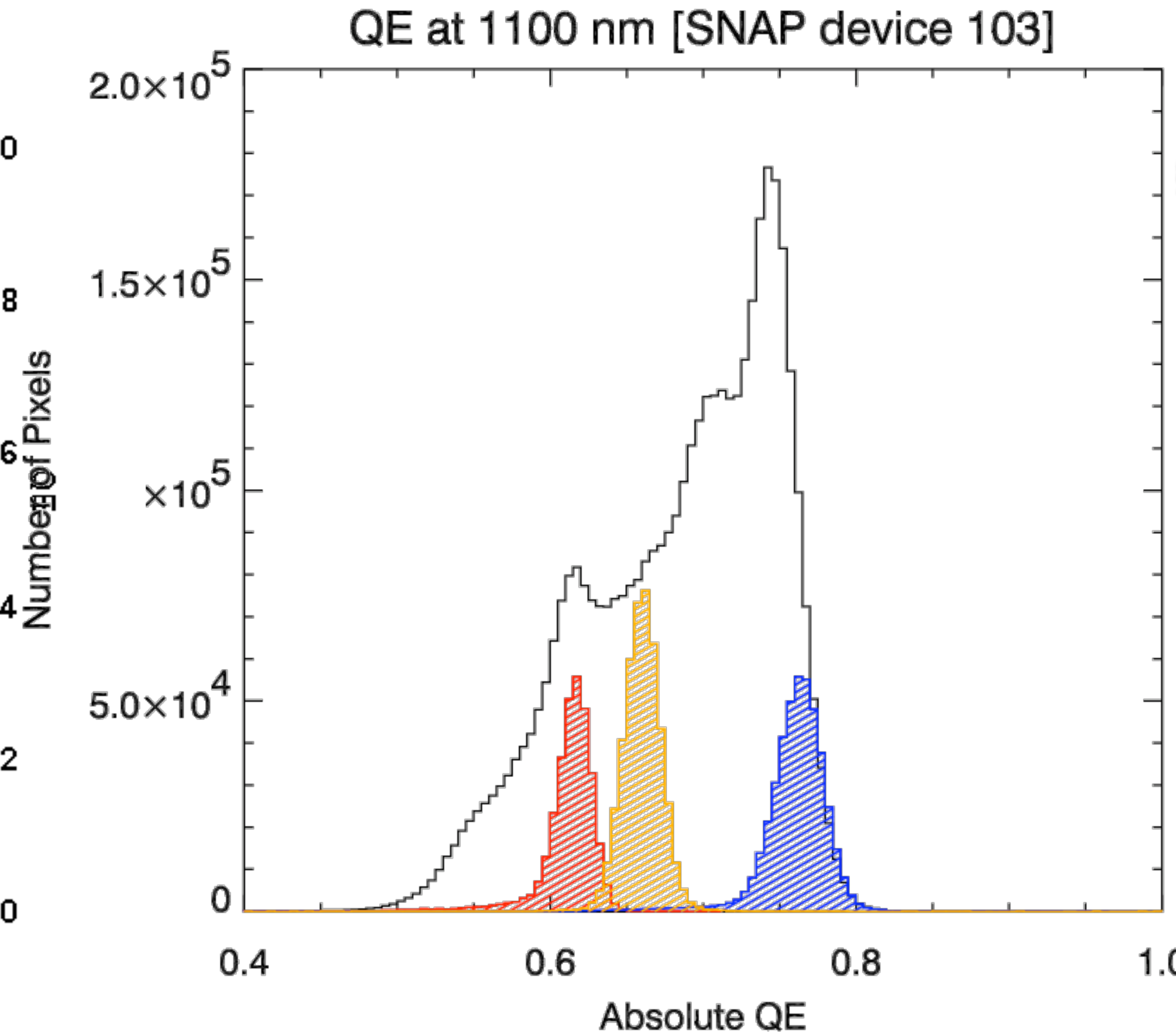
PIX (QE>50%): 99.9⁴



but .....

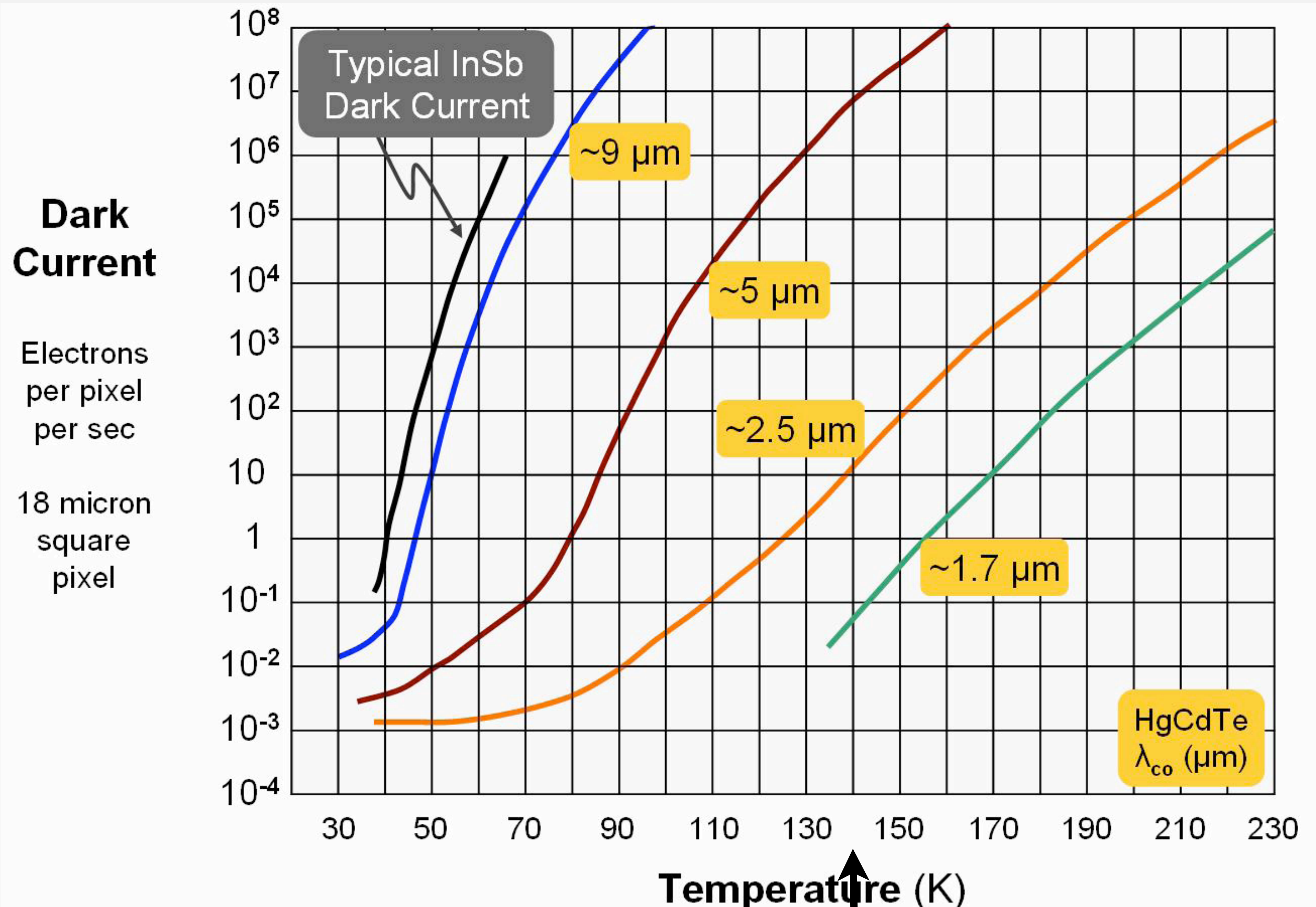


QE Map @ 900nm
U. Michigan Detector R&D
2000
1500
1000
500
0
0
500
1000
1500
2000
1.0
0.8
0.6
0.4
0.2
0.0

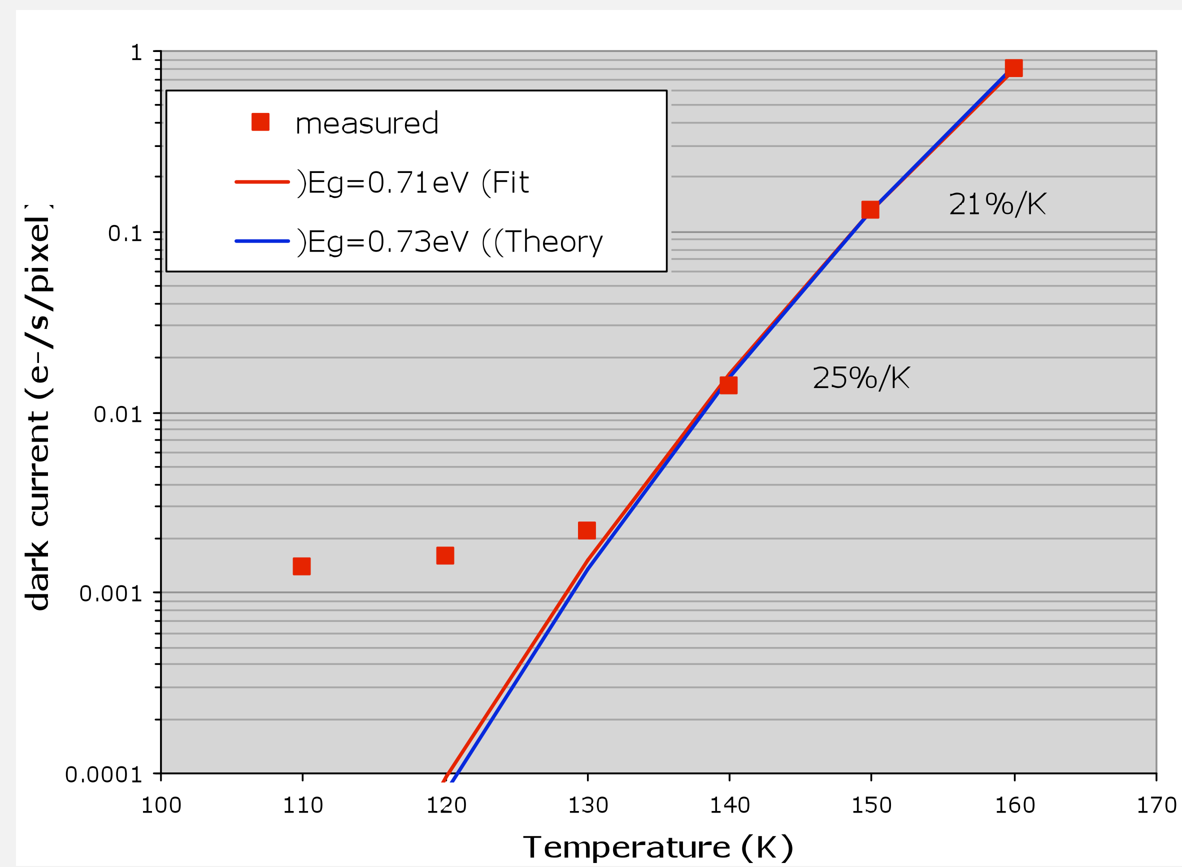


QE at 1100 nm [SNAP device 103]
Number of Pixels
Absolute QE
0.4
0.6
0.8
1.0

Dark Current

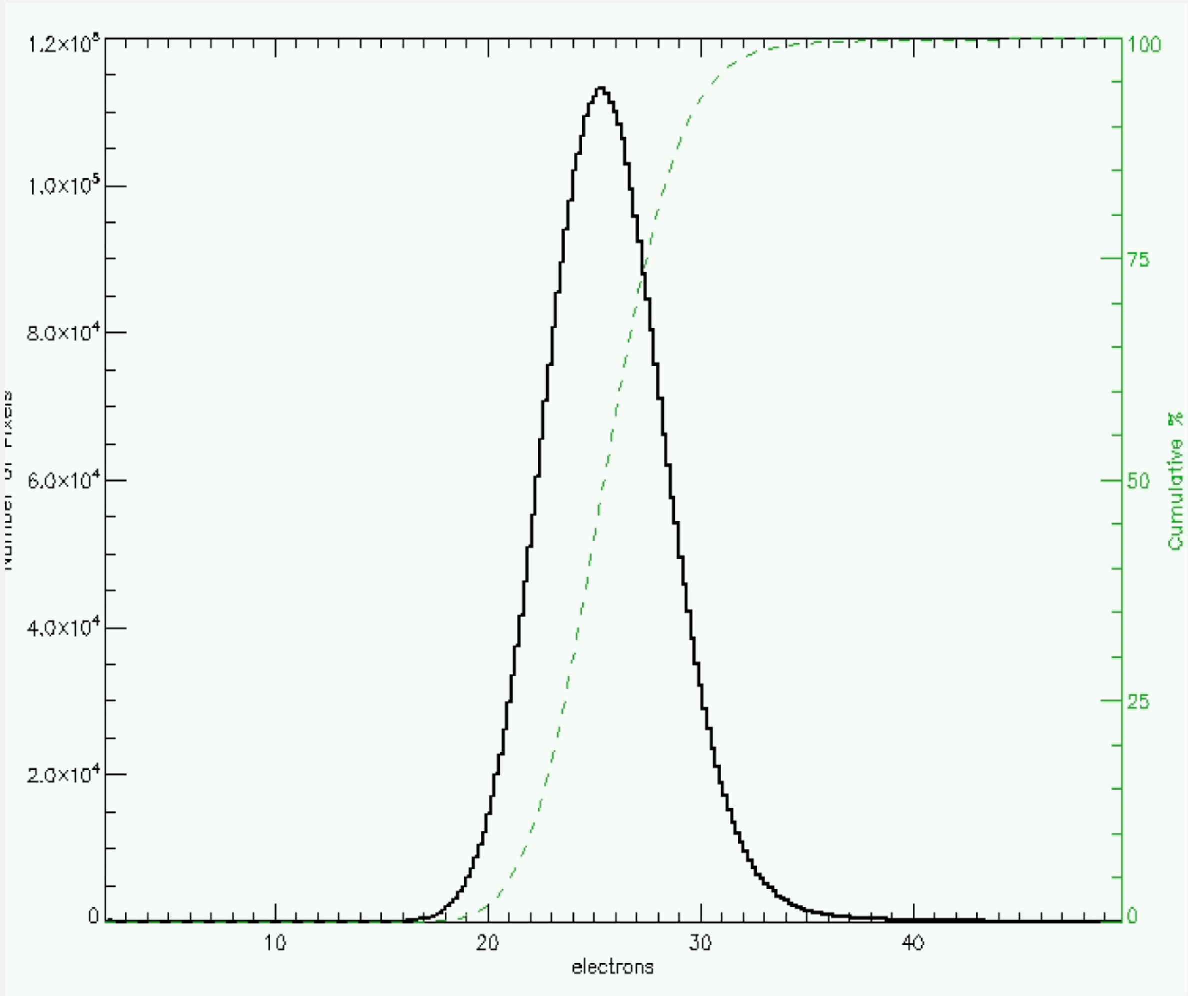


nominal SNAP temp.



low dark current requires cooling

Read Noise

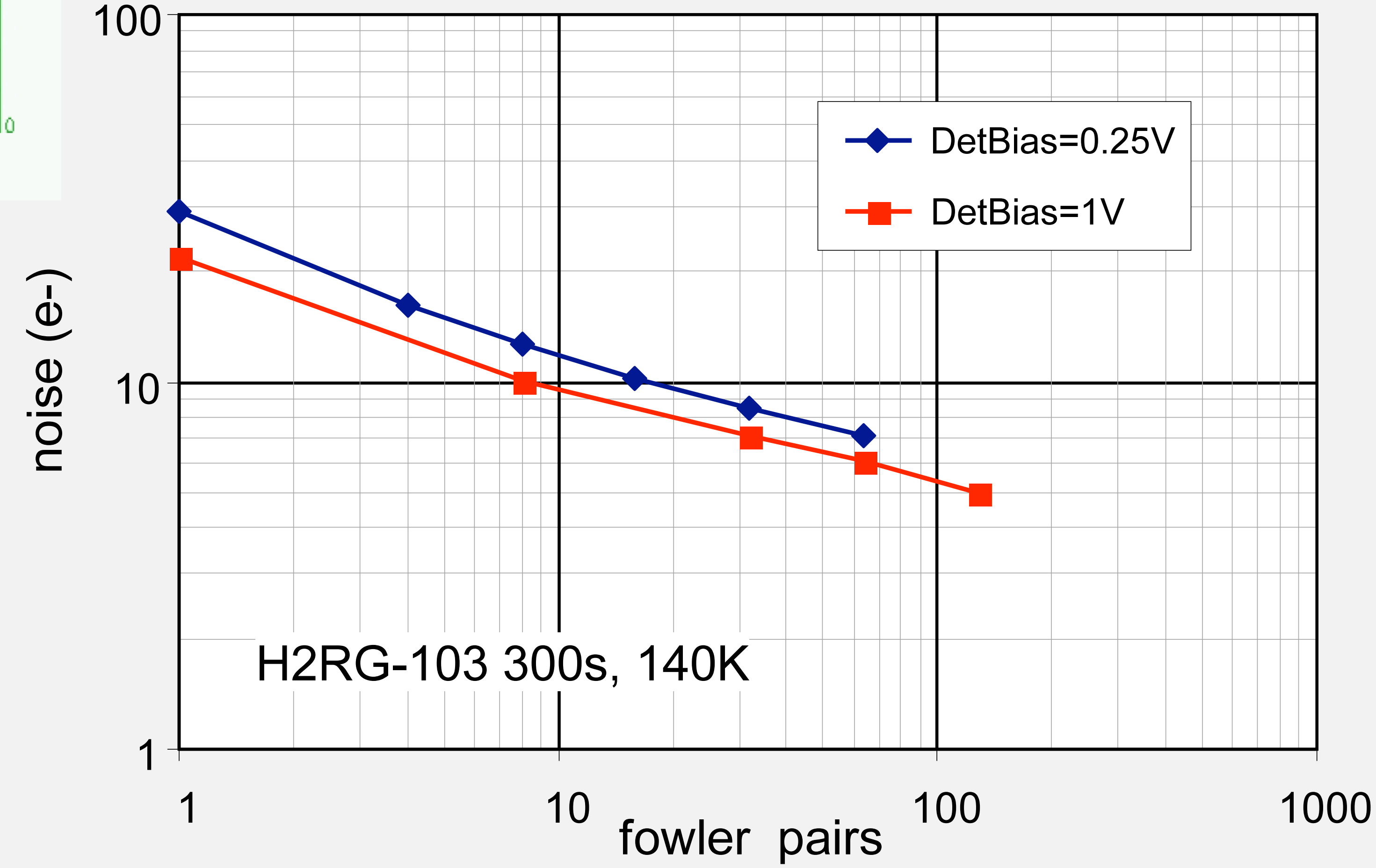


SNAP 1.7 micron detectors

typical

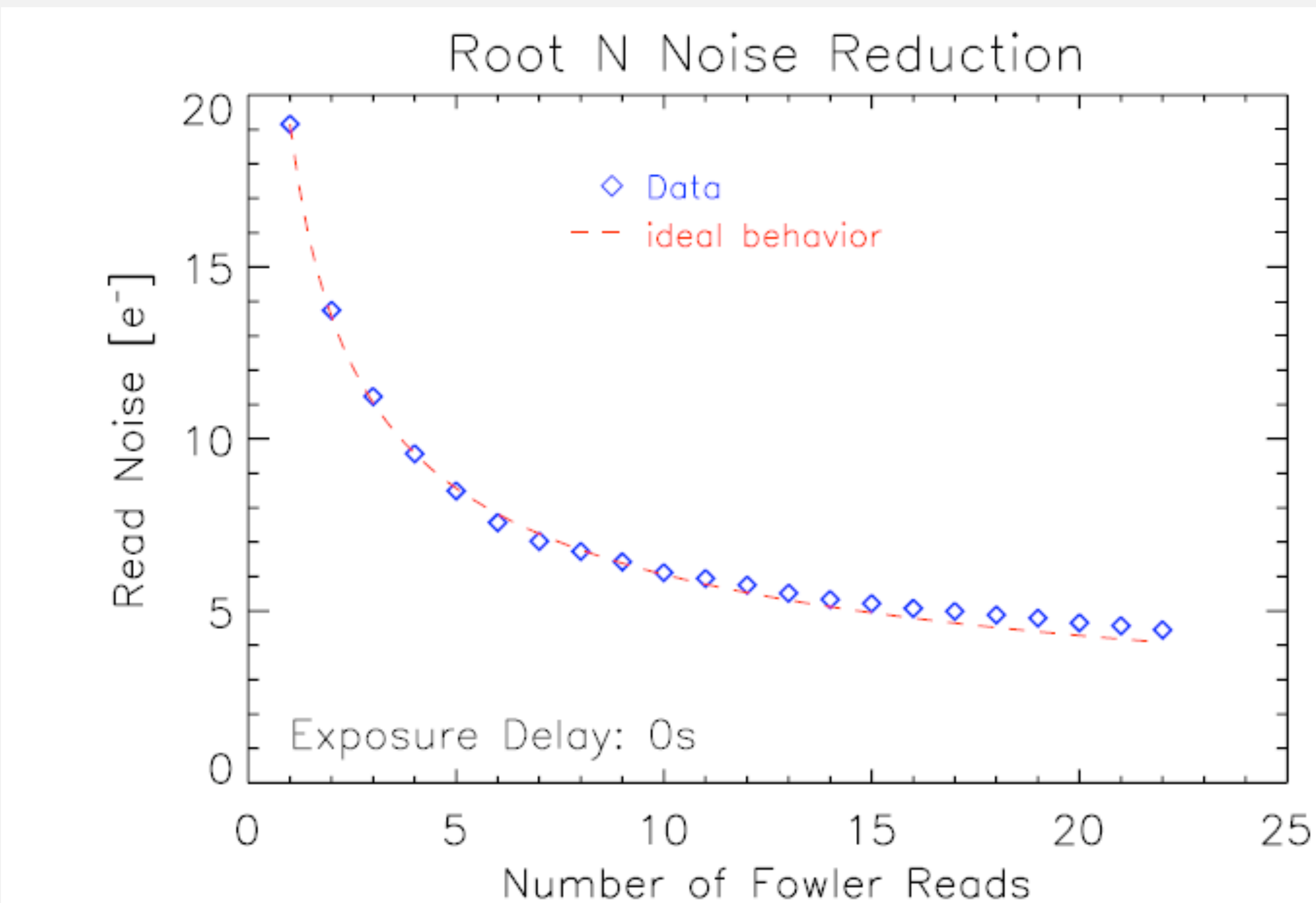
CDS read noise

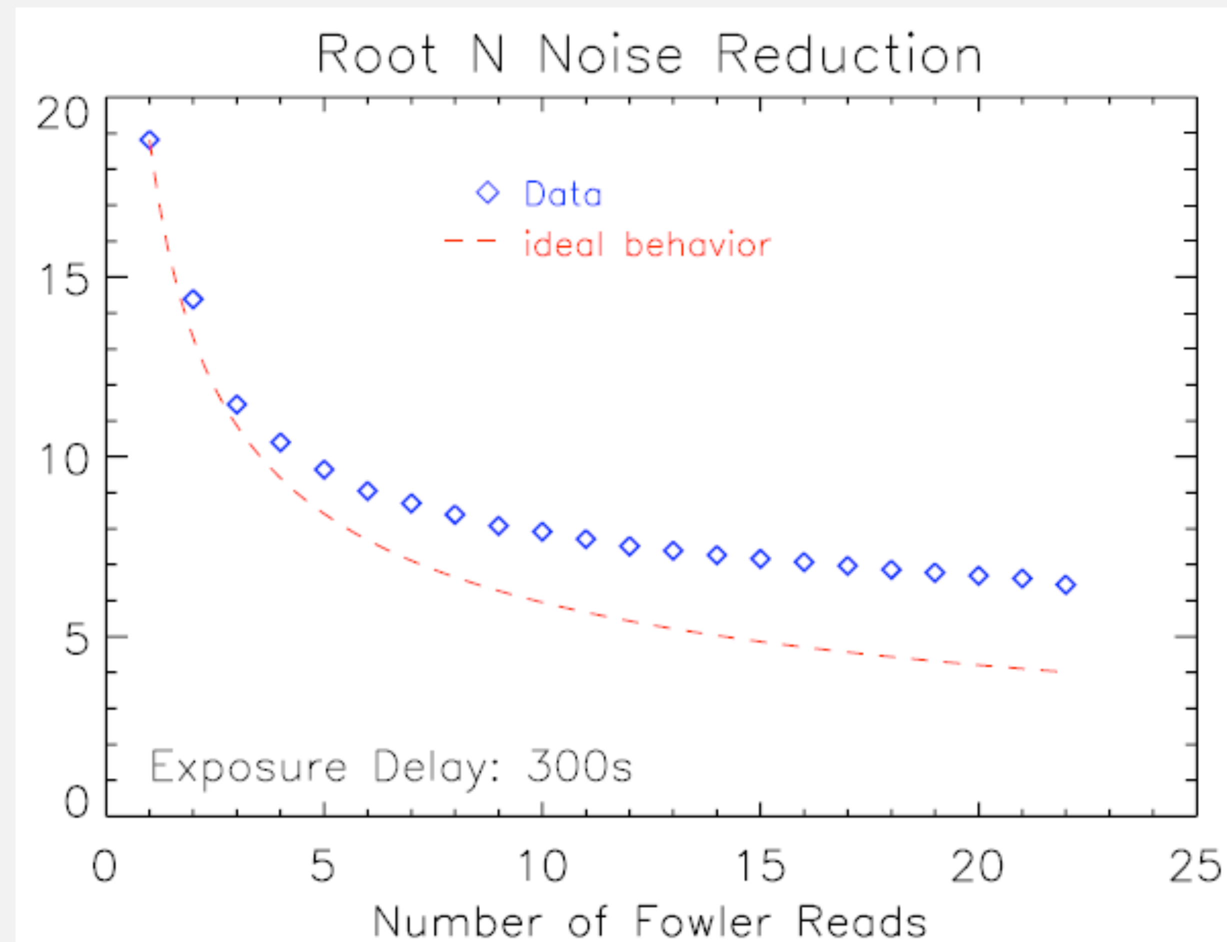
~25 e



Read noise reduction through multiple sampling

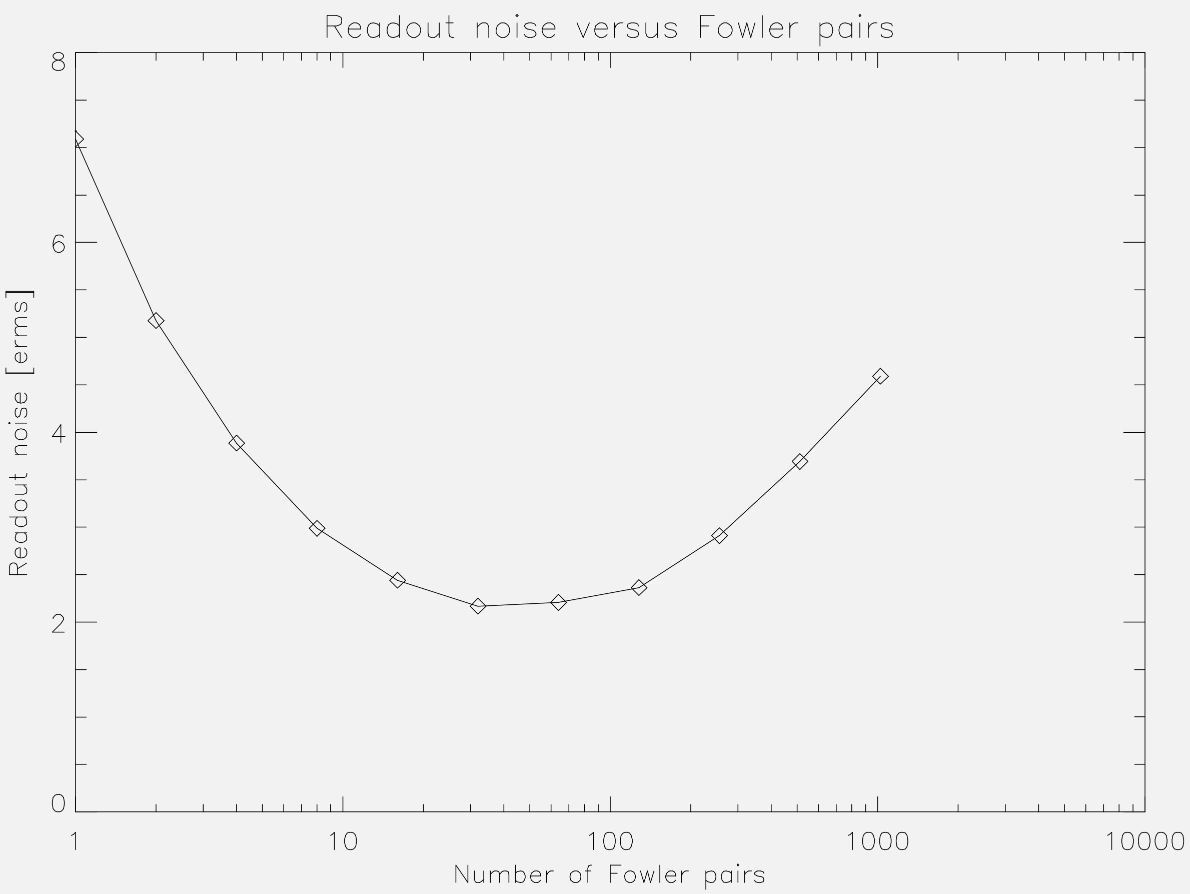
Fowler-N sampling:

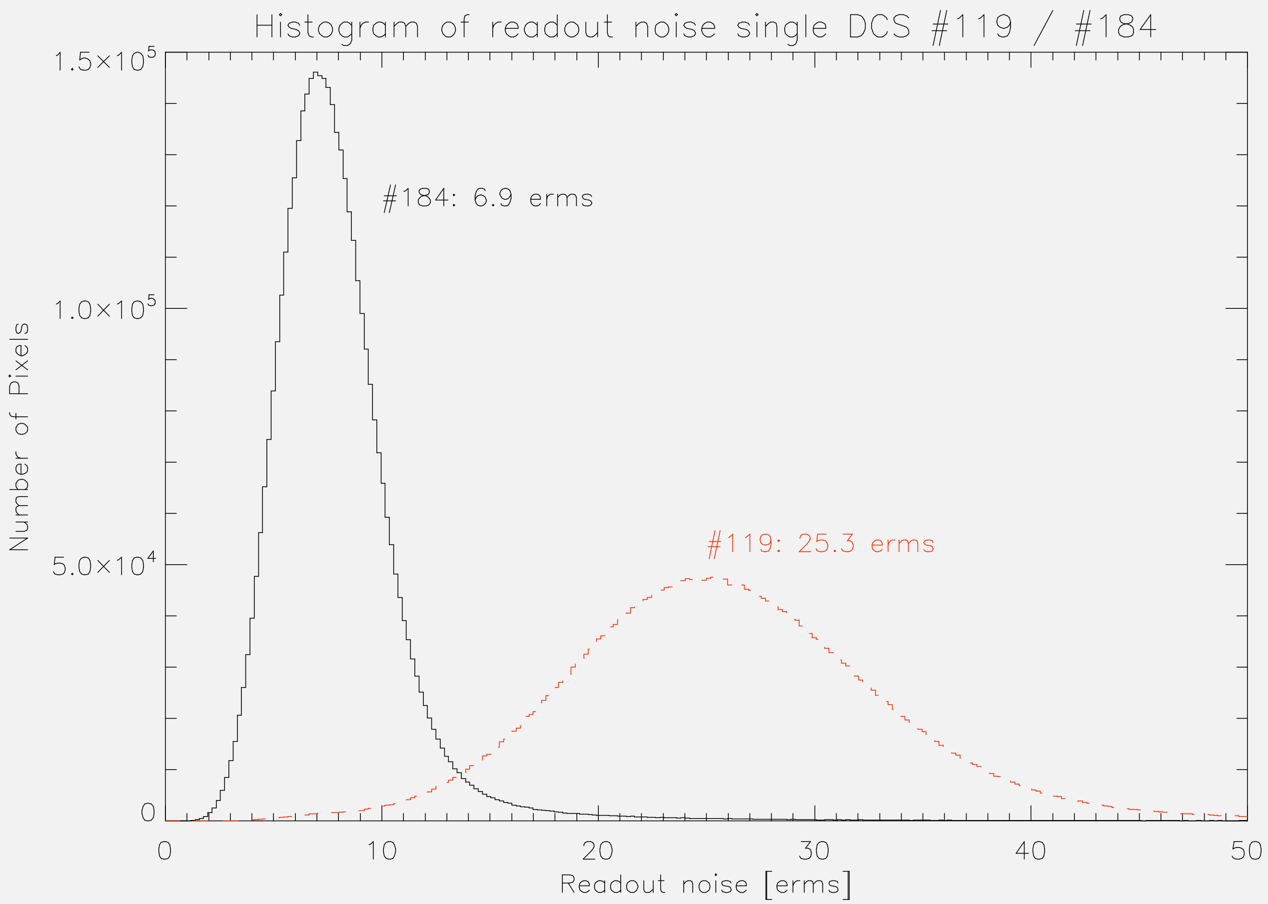




Dark current limits $\sqrt{N}$ read-noise floor

2.5 micron material shows superior read-noise performance





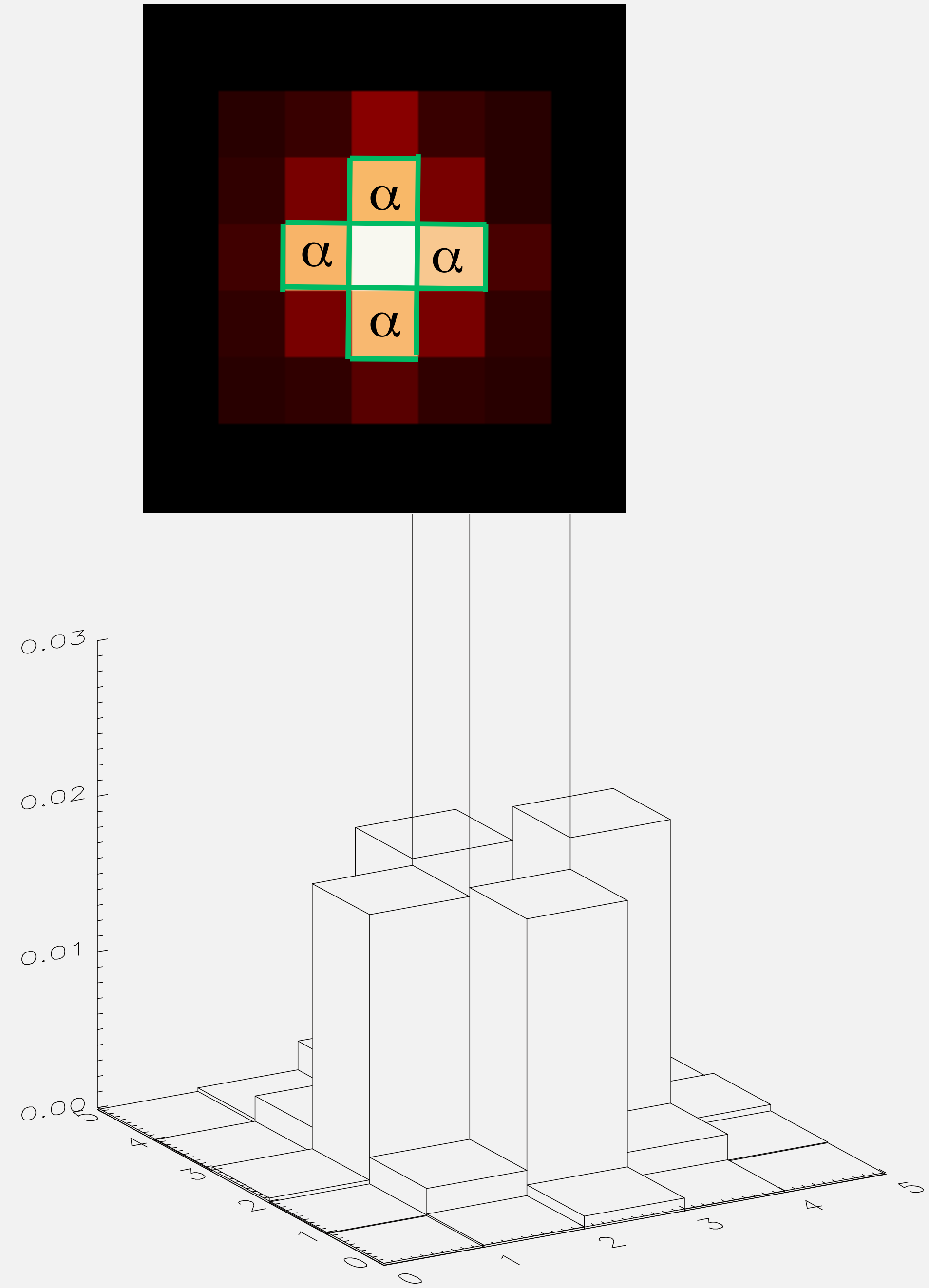
2.2 e for Fowler-32

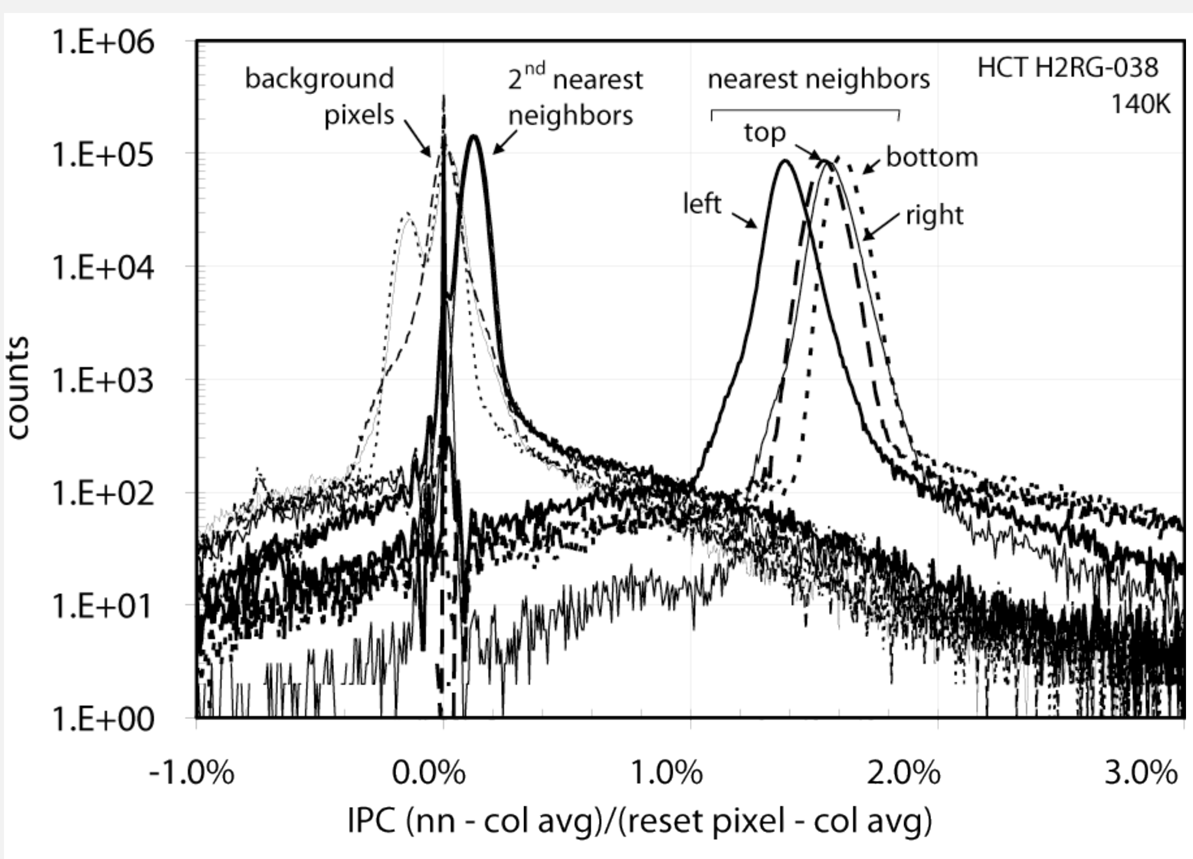
Lower read noise can be achieved by increasing cutoff wavelength BUT

- for long exposures dark current becomes problematic
- higher cut-off wavelength requires significant lower temperature (to keep DC low)

Inter-pixel capacitance

capacitively couples the signal in a pixel to its four nearest-neighbor pixels.



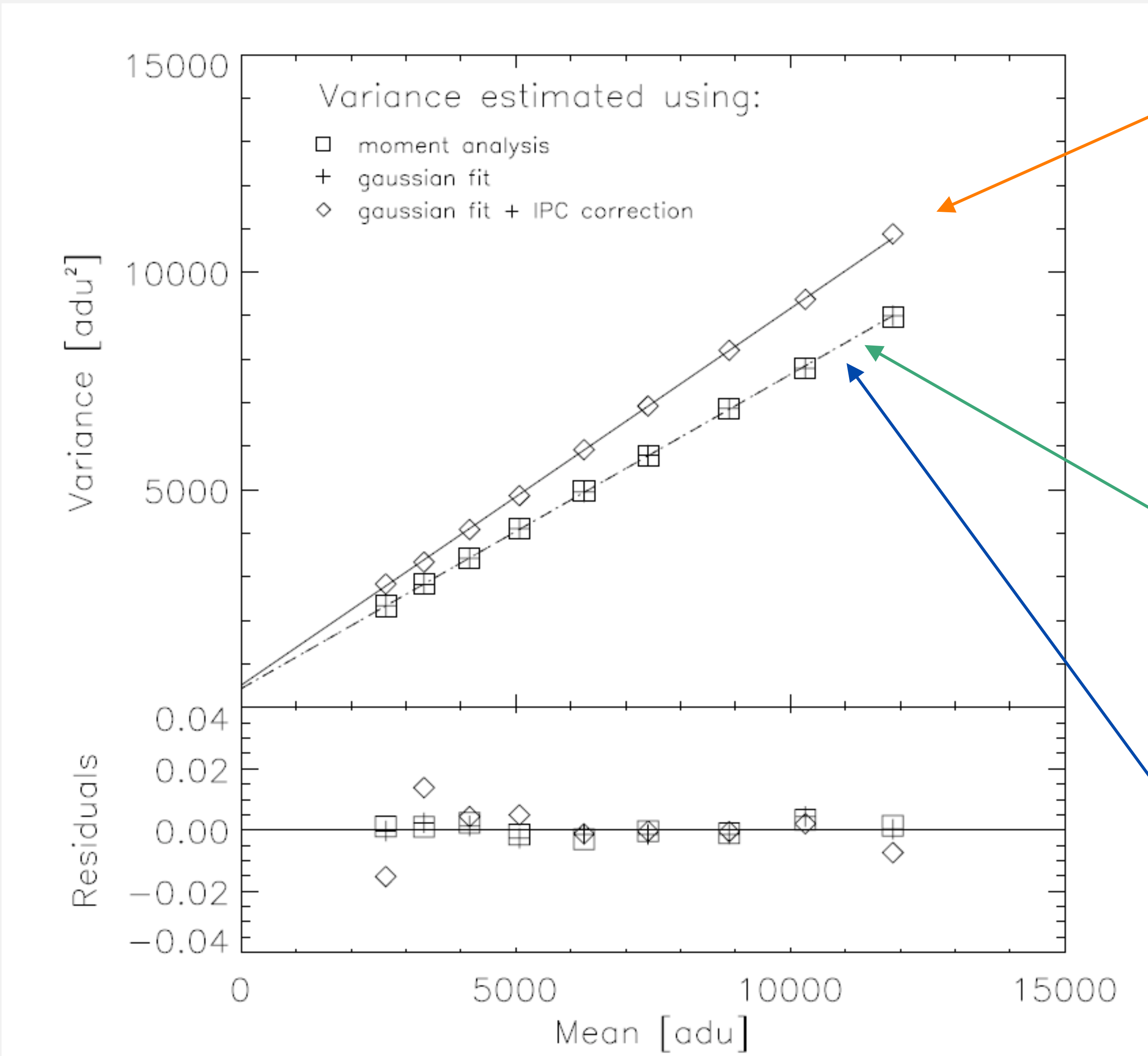


Efforts under way to reduce IPC

For Teledyne ... alpha=1.5

Conversion Gain Measurement

Gain is measured with 3 techniques



Ignoring correlated noise over-estimates the gain by ~ 20%. (for this device)

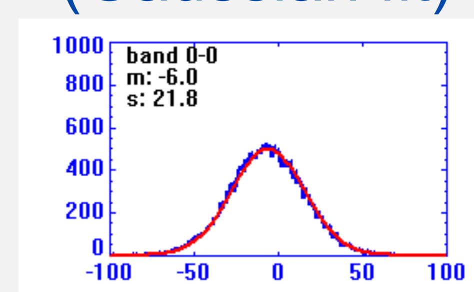
variance estimator accounts for IPC

$$\widehat{\sigma_D^2} = \frac{1}{2N}\left[\sum_{i,j} D^2[i,j] + 2\sum_{i,j} D[i,j]\,D[i+1,j] + 2\sum_{i,j} D[i,j]\,D[i,j+1]\right]$$

traditional variance estimator

$$\widehat{2\sigma_N^2} = \widehat{D^2} = \frac{\sum_{i,j} D^2[i,j]}{N}$$

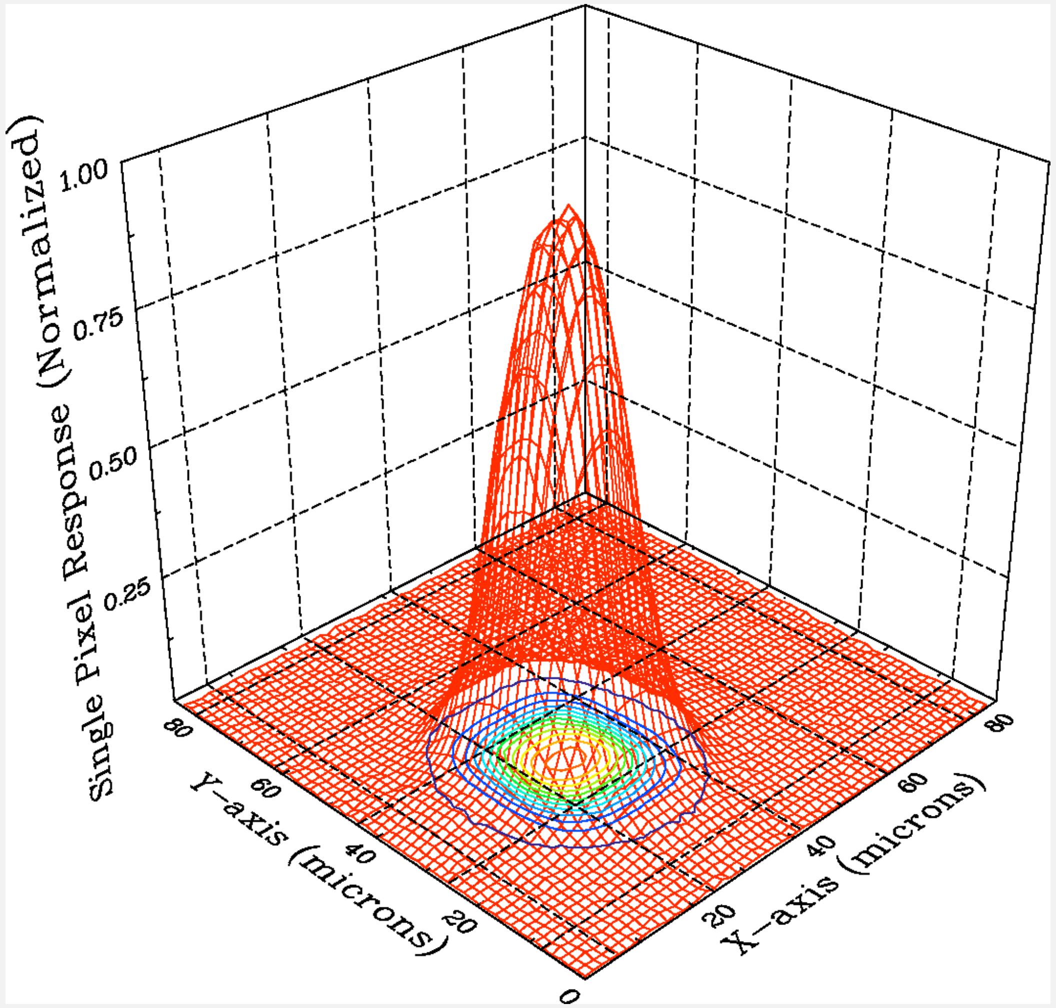
standard gain measurement (Gaussian fit)

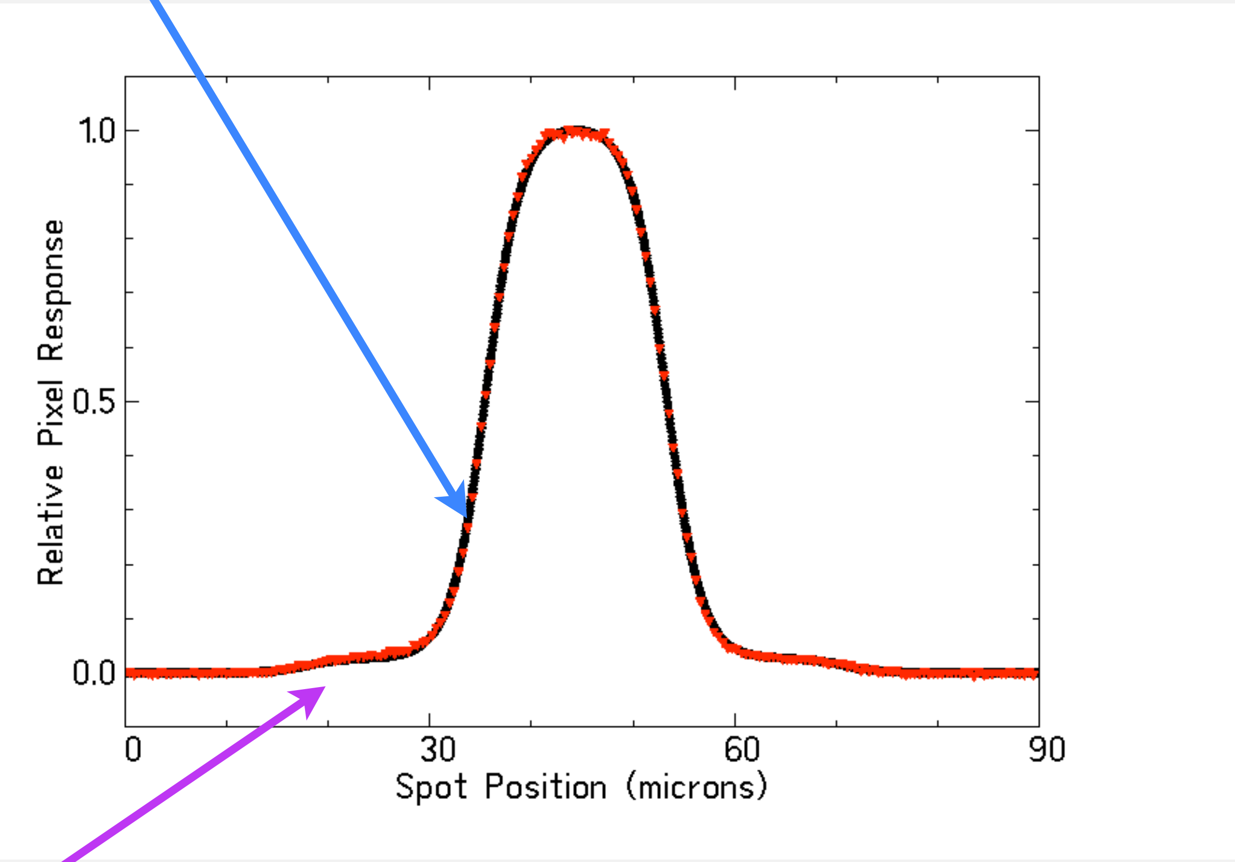


Agreement between **Gaussian** and **standard variance** methods confirms that outliers have been properly masked.

INTRA-PIXEL RESPONSE

lateral charge diffusion
(random, prior to charge collection)



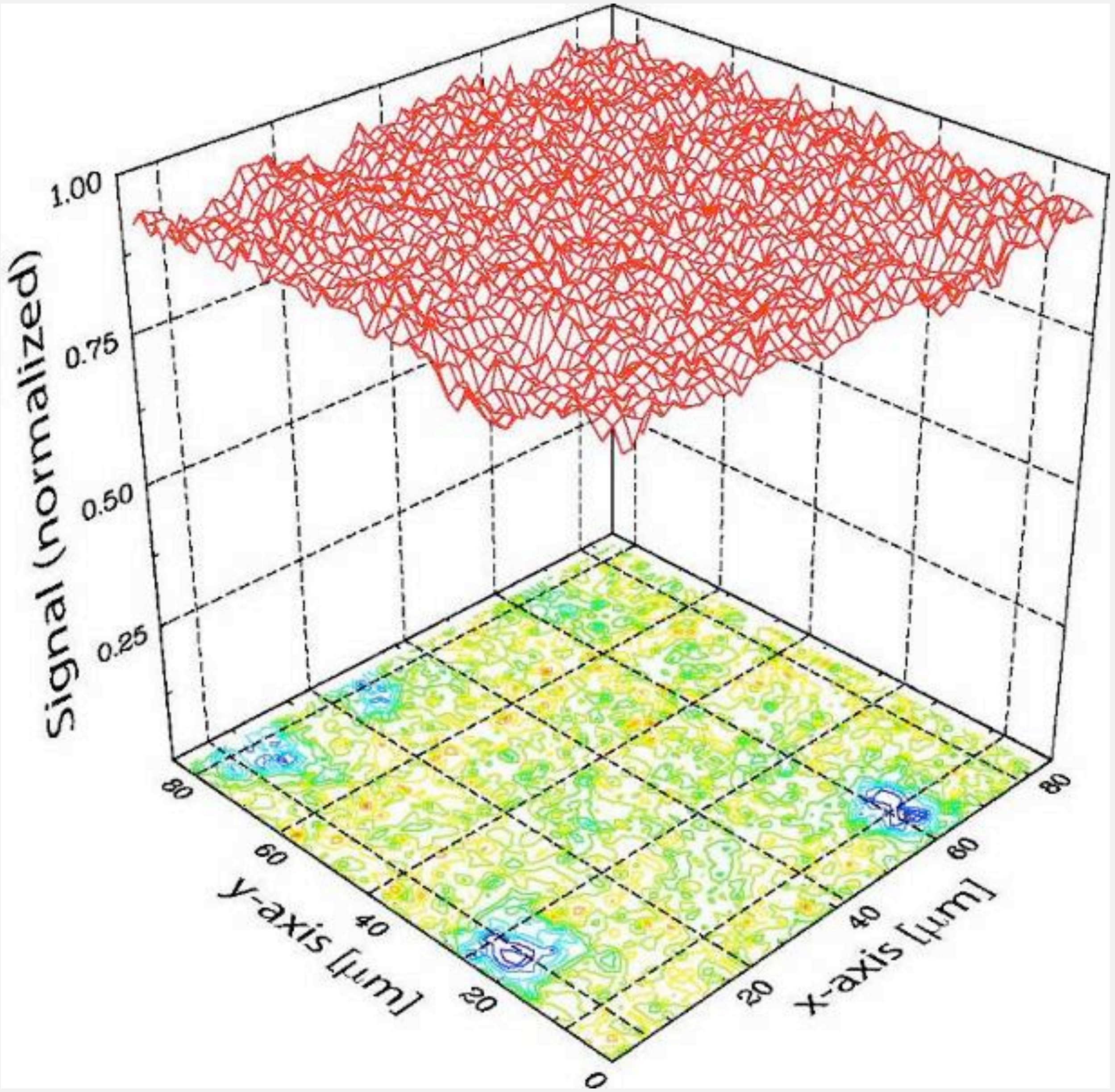


capacitive coupling
(deterministically moves
charge after collection)

fitted pixel parameters:

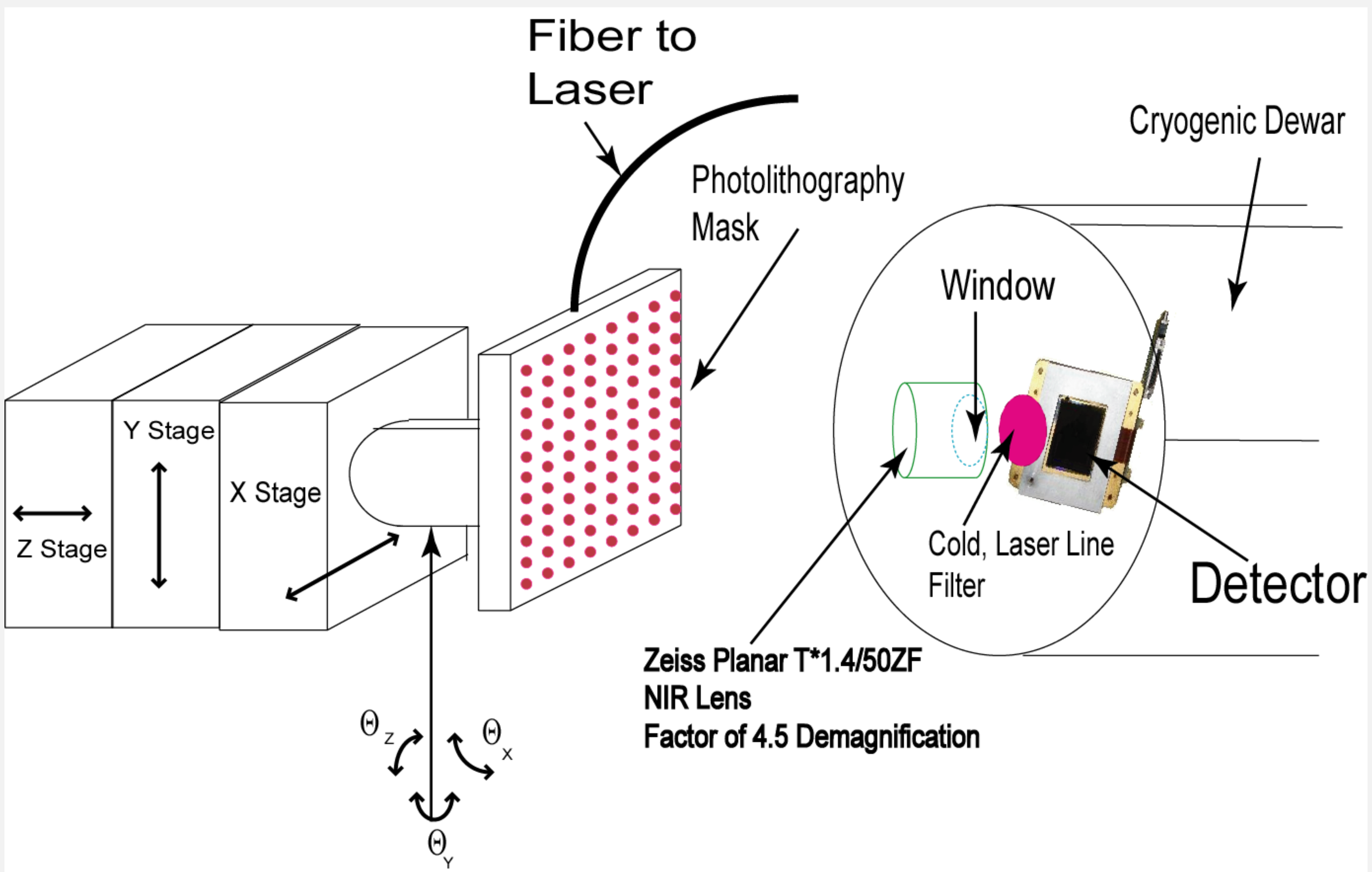
charge diffusion: 1.7 ± .02 μm
capacitive coupling: 2.4 ± .1%
(from correlated noise: 2.2 ± .1%)

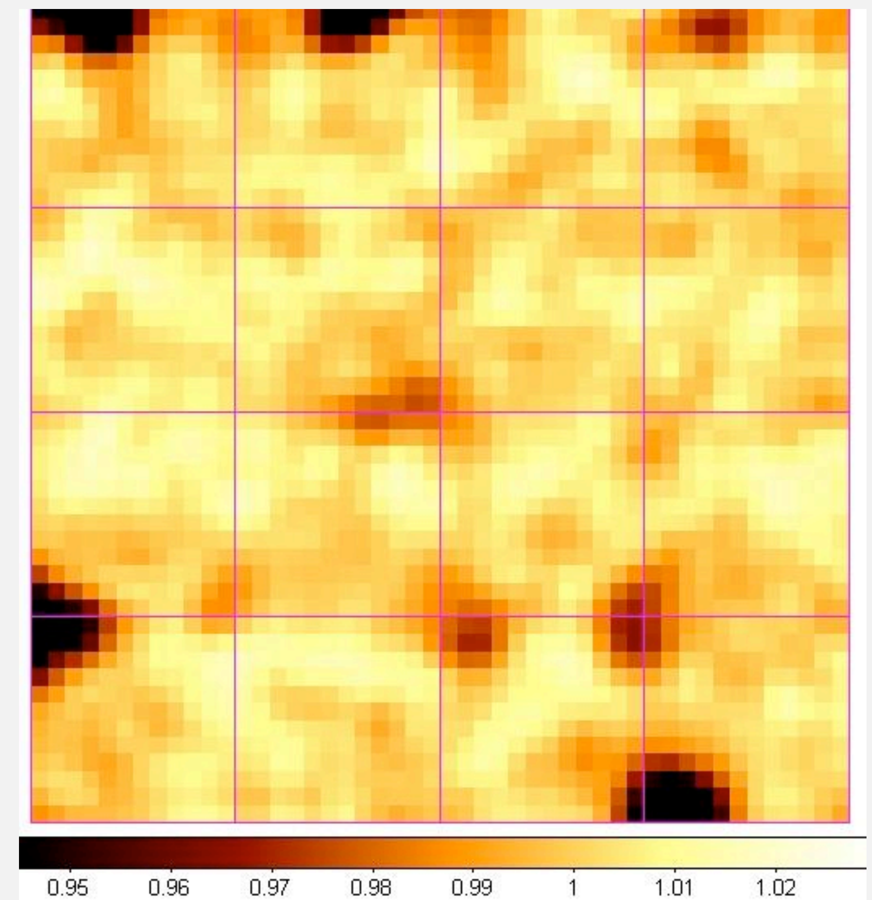
Pixel Level Response



Spot's'-o-Matic

Simultaneously scan array of (400 x 400) spots to rapidly characterize the sub-pixel response of an entire detector

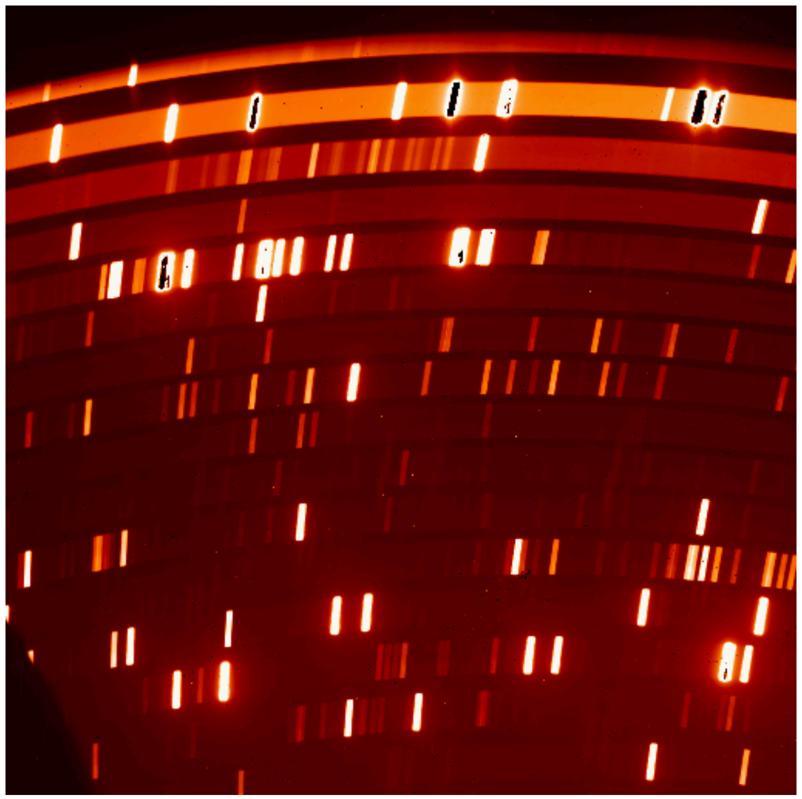




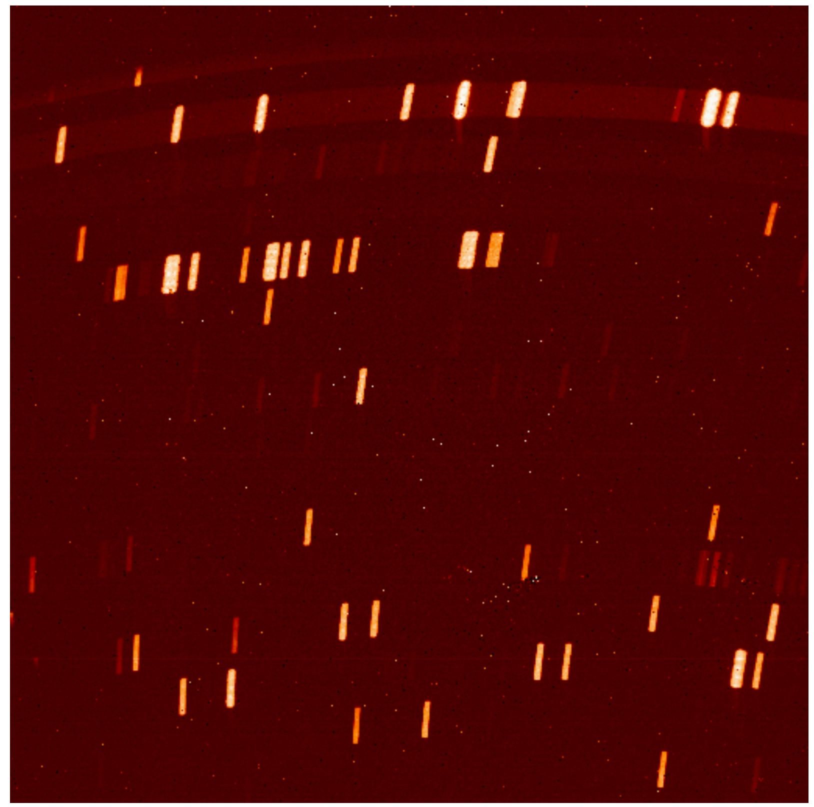
Simulated Spot*s*-o-Matic signal obtained by convolving Spot-o-Matic Scan with 6μm PSF

Persistence

"ghost" of previous exposure in the current exposure.



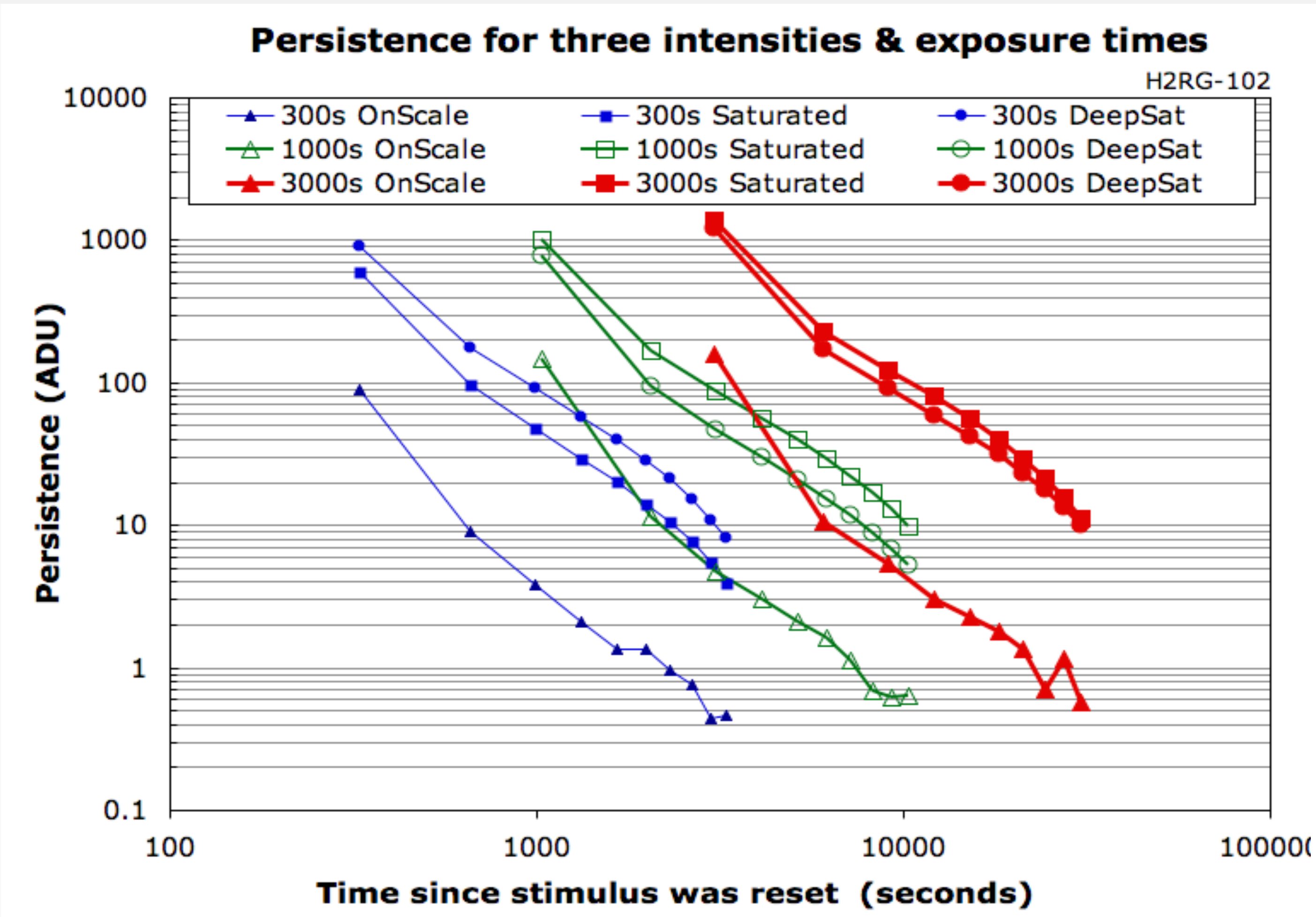
Slit open



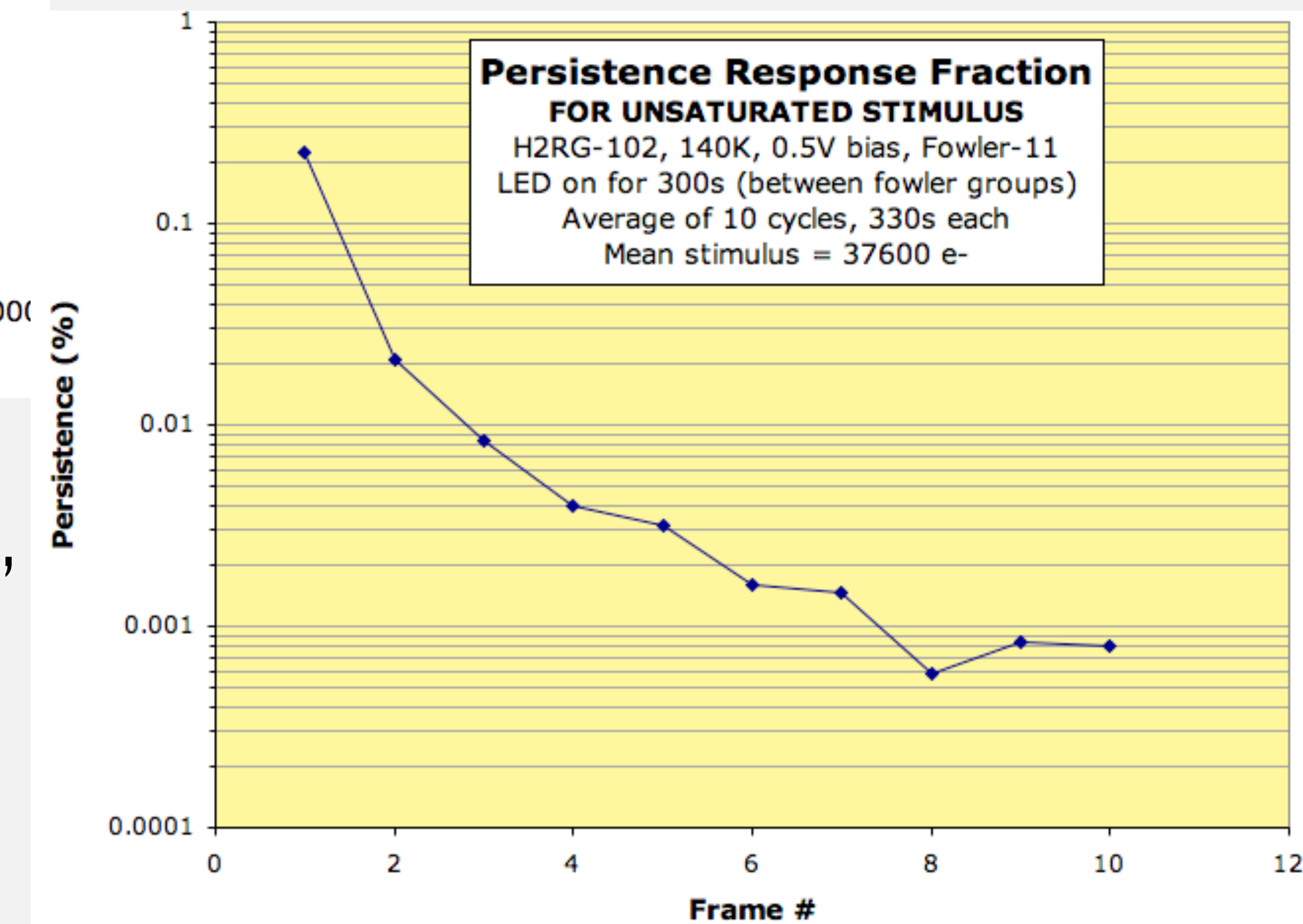
First 2 minute dark exposure

Persistence

similar decay shape for different fluence and exposure time

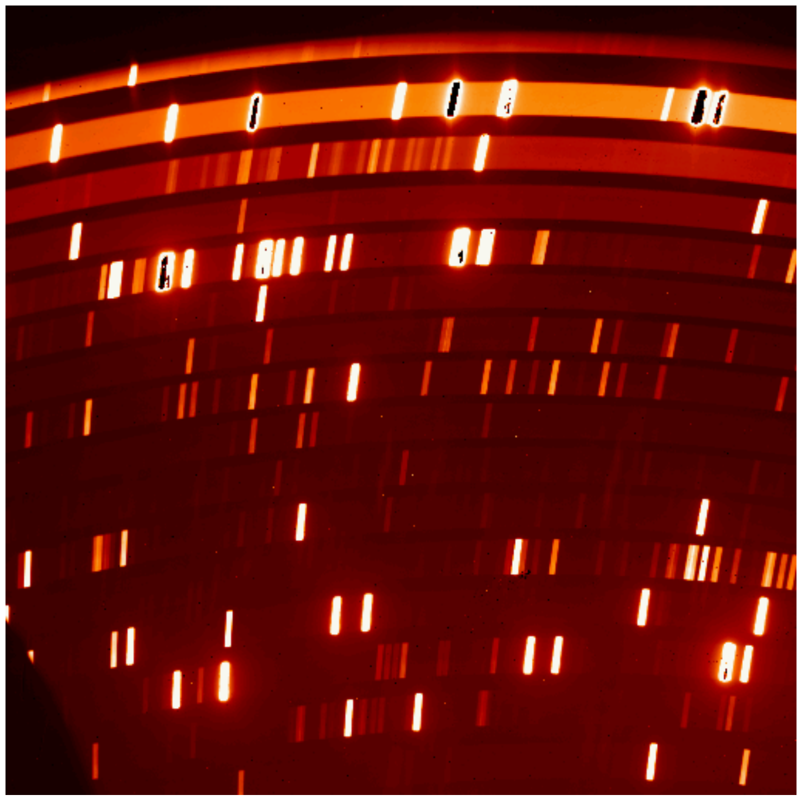


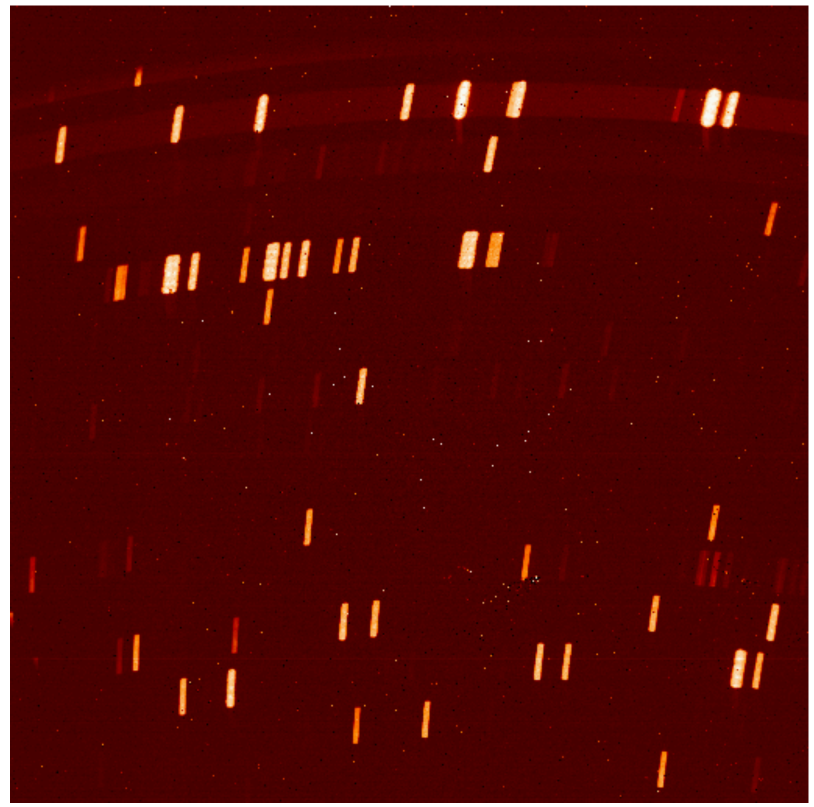
Can obtain 'persistence curve'
(for fixed exposure time)

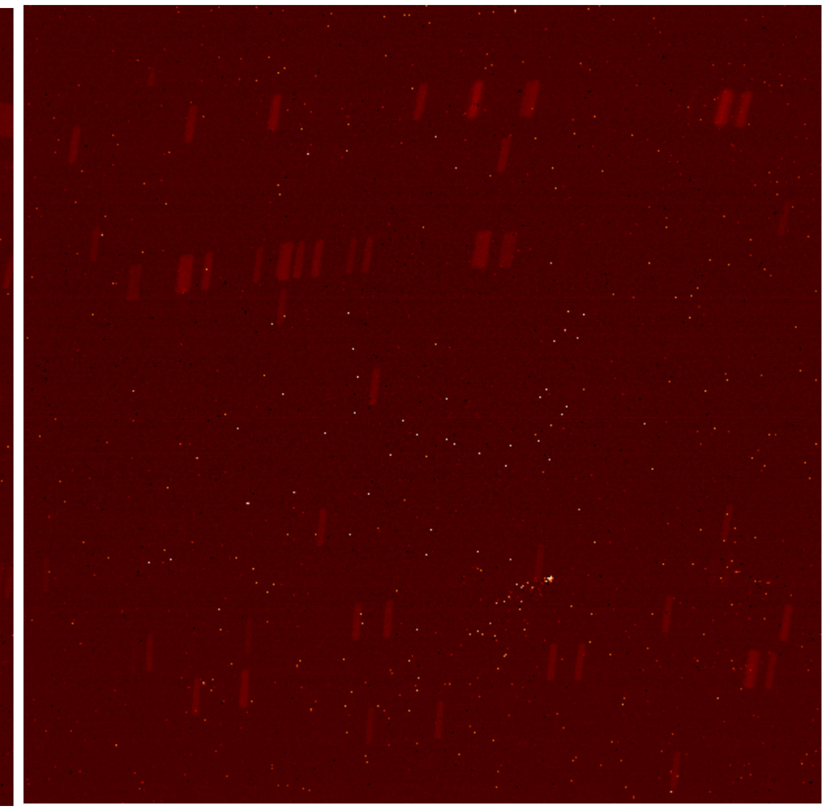


Mitigation of Persistence

(measurement by Gert Finger following persistence model by Roger Smith)







- First 2 minute dark exposure without global reset de-trapping

- First 2 minute dark exposure with global reset de-trapping

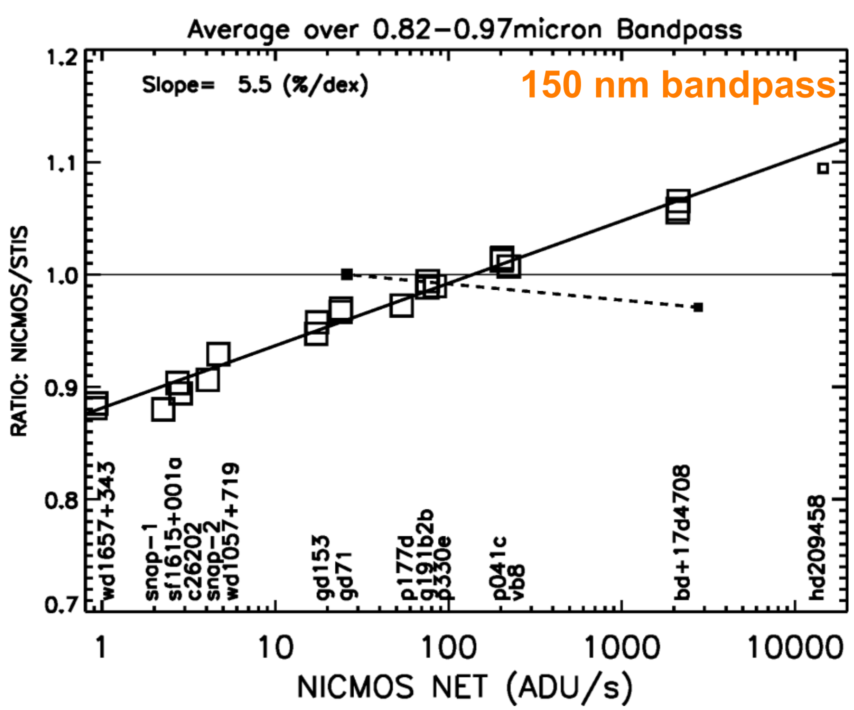
Slit open

factor 9 improvement

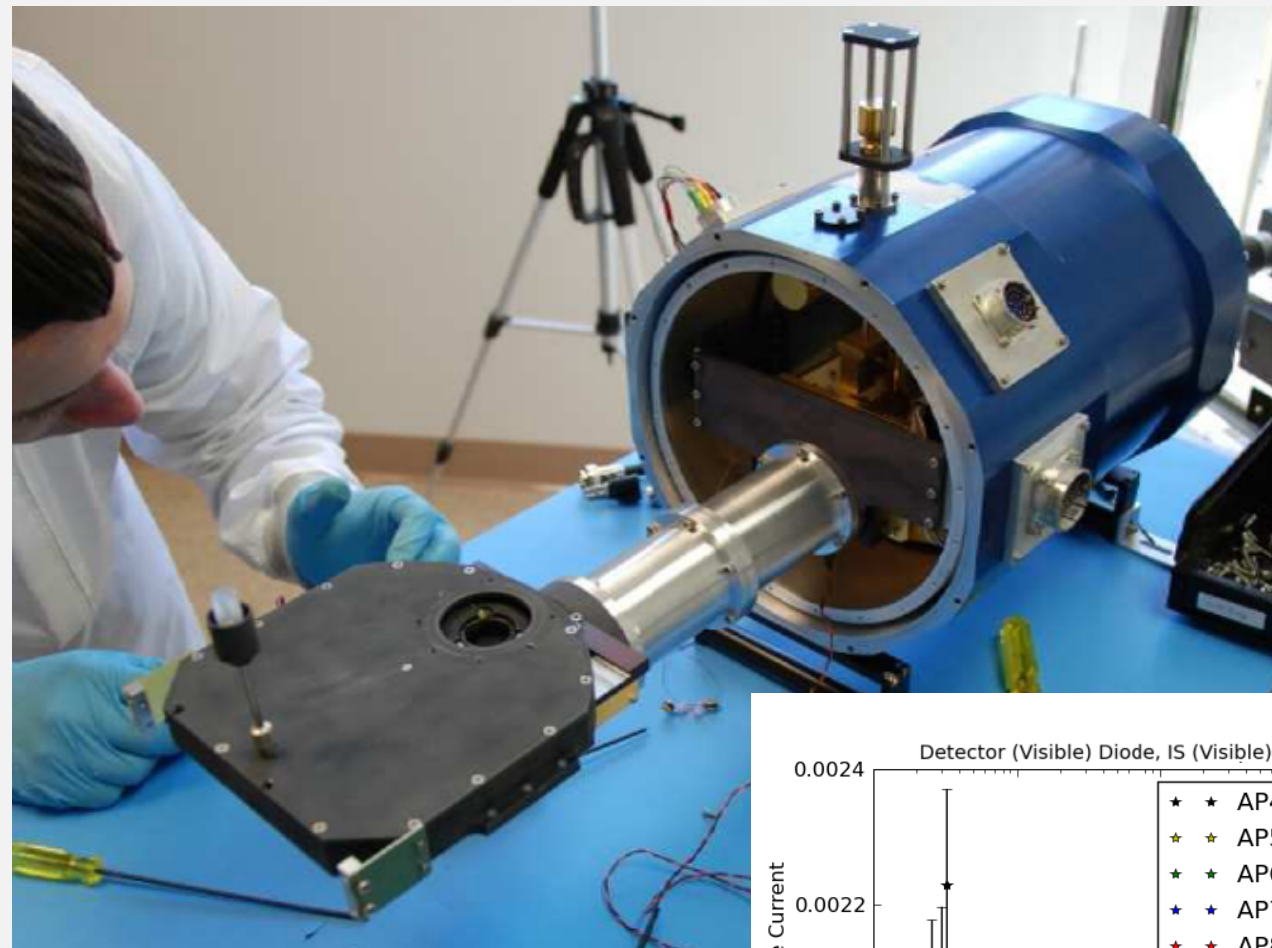
Reciprocity Failure

(bright source - short integration time does not give the same signal as dim source - longer integration time)

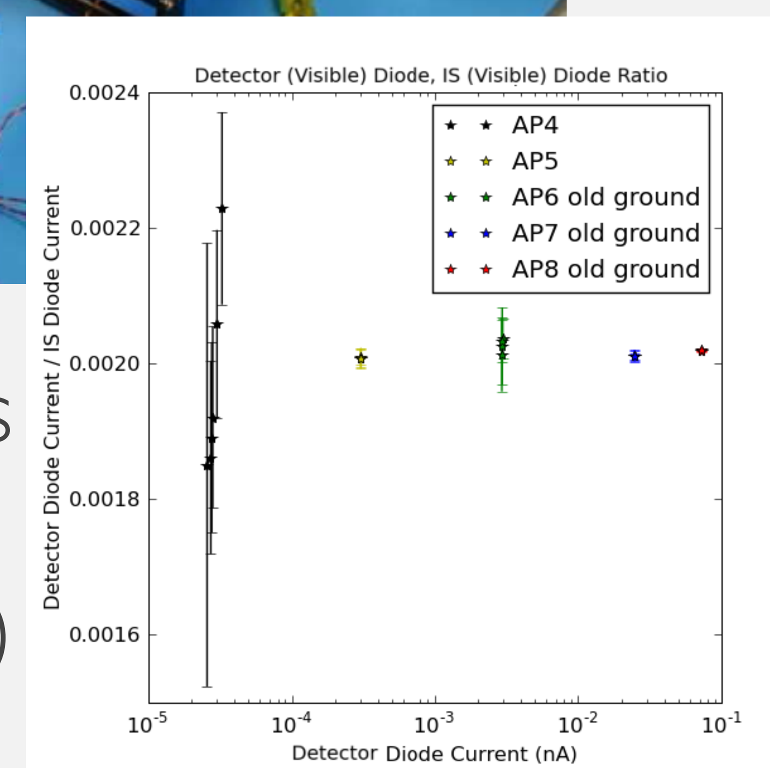
- NICMOS arrays (2.5 mm cut-off HgCdTe) on HST exhibit a 5-6%\dex flux dependent non-linearity



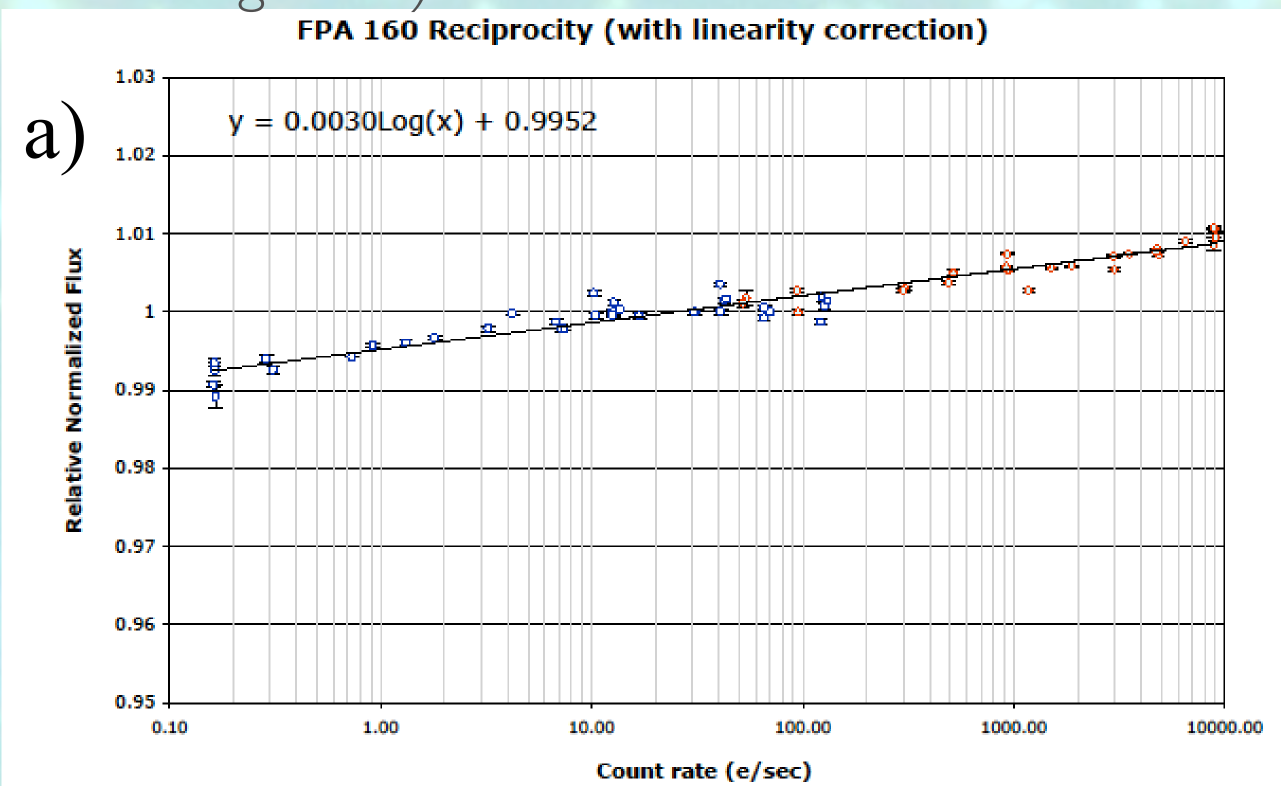
- exhibits power law behavior, with pixels with high count rates detecting slightly more flux than expected for a linear system (and vice-versa).

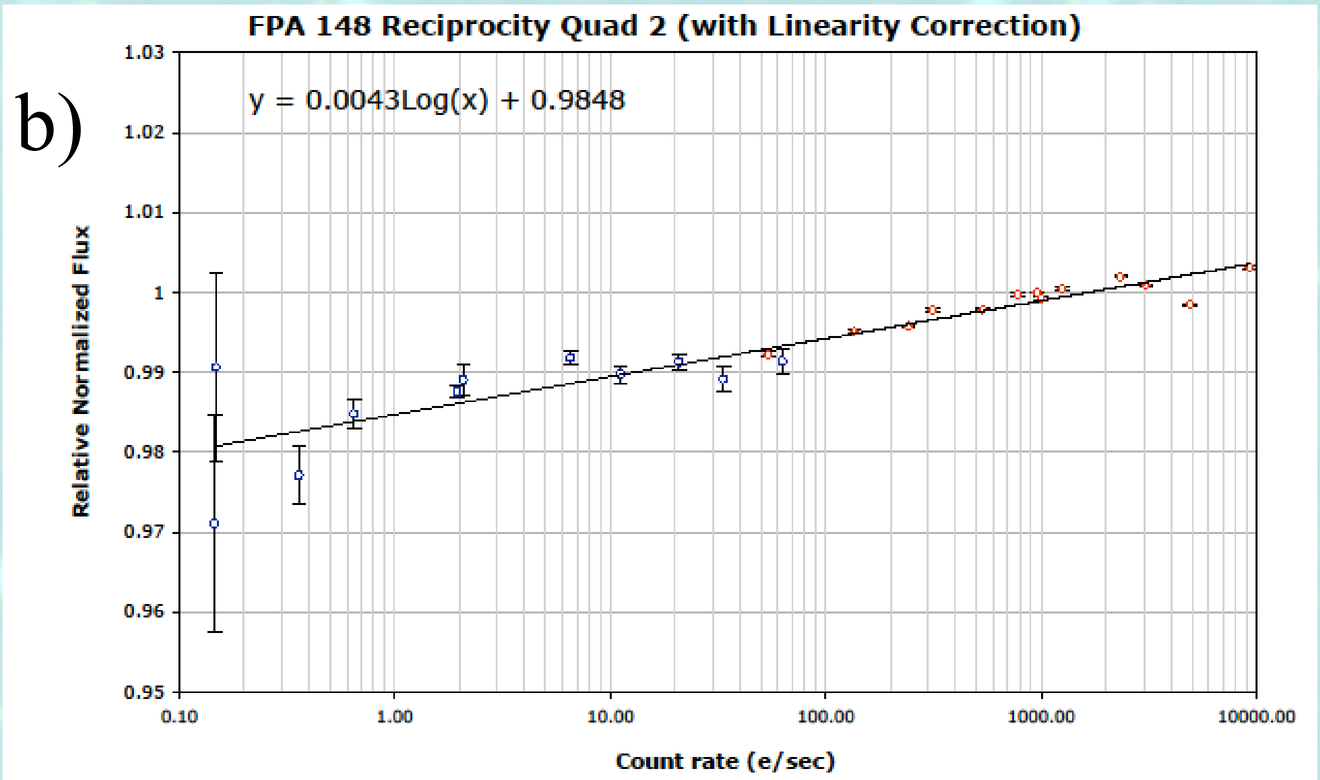


illuminated pinholes calibrated over 5 decades (0.2%/dex)



Reciprocity failure reported by WFC3 group (1.7 micron) (Bob Hill, DfA Garching 2009)





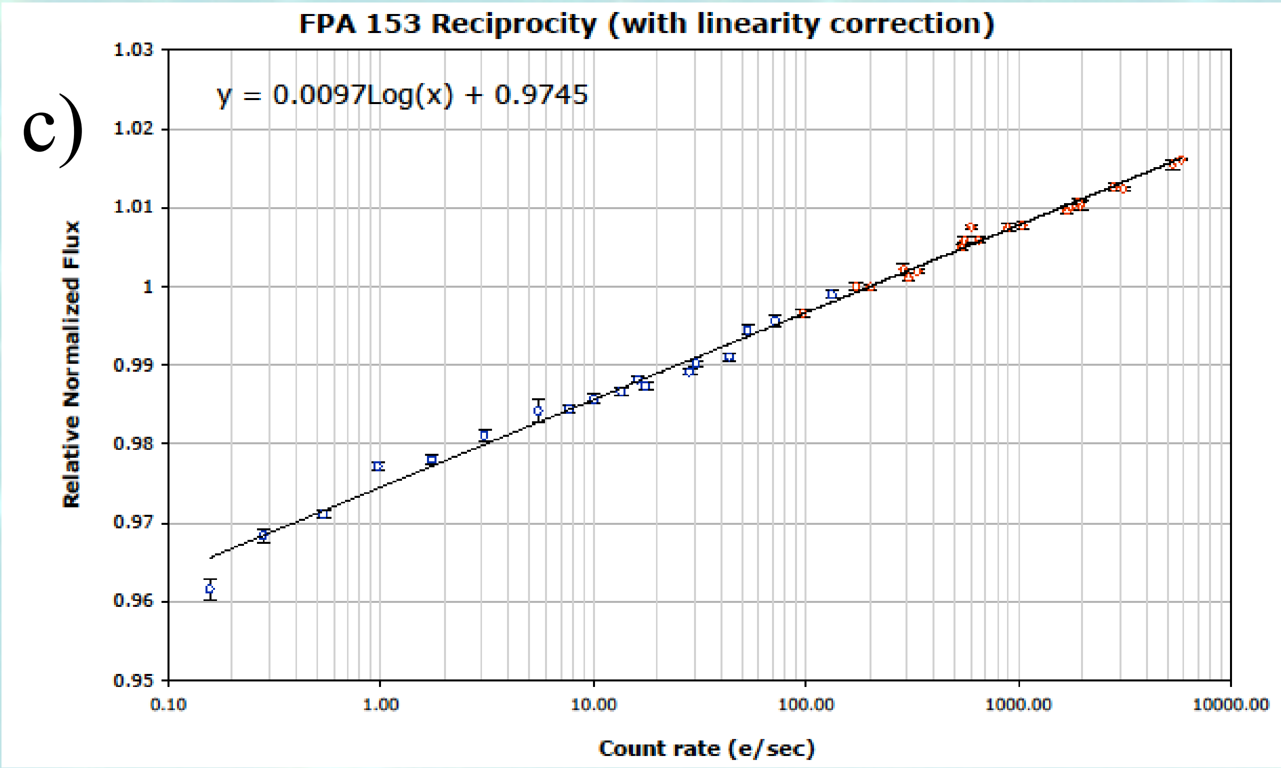
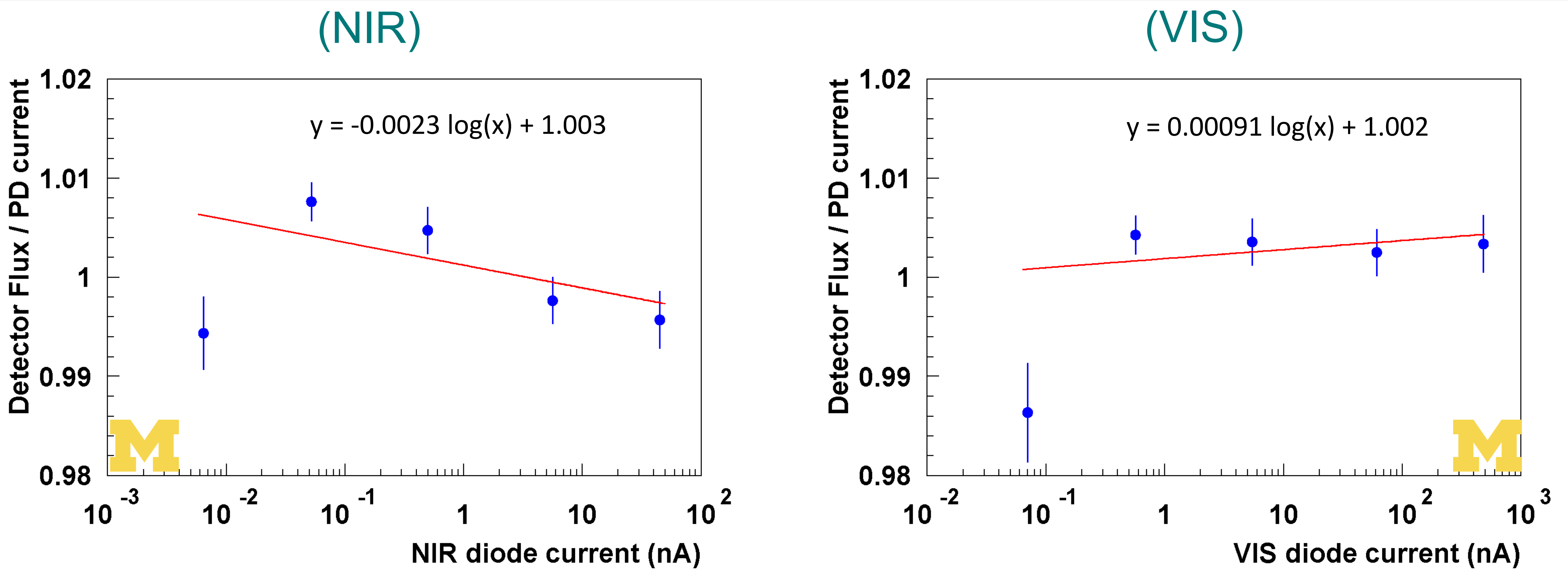


Figure 4a-c. The reciprocity failure observed in three different detectors: a) FPA160, b)FPA148, and c) FPA153. In all cases, the flux-dependent response obeys a power law over the range of fluxes tested, although the slope varies from detector to detector.

0.3%/dex to 0.97%/dex ... much smaller than NICMOS effect

So far no indication for reciprocity failure in SNAP 1.7 micron device measured at UM



- The response of H2RG #102 (1.7 mm cut-off HgCdTe) is (-0.23±0.1)%/dex (NIR) and (0.091±0.097)%\dex (Vis) as input flux increases

  → slight difference between NIR and Vis PD calibrations

  → but overall smaller than 0.25%\dex

Summary

Much NIR Expertise gained from SNAP program
NIR lab at UM capable of precise (% level) characterization

Selection of detector material (2.5 vs 1.7) requires trade studies
Lowest read-noise w/ 2.5 micron material but requires much
lower temperature than 1.7 micron material

Fast, compact read-out in hand

THANK YOU !